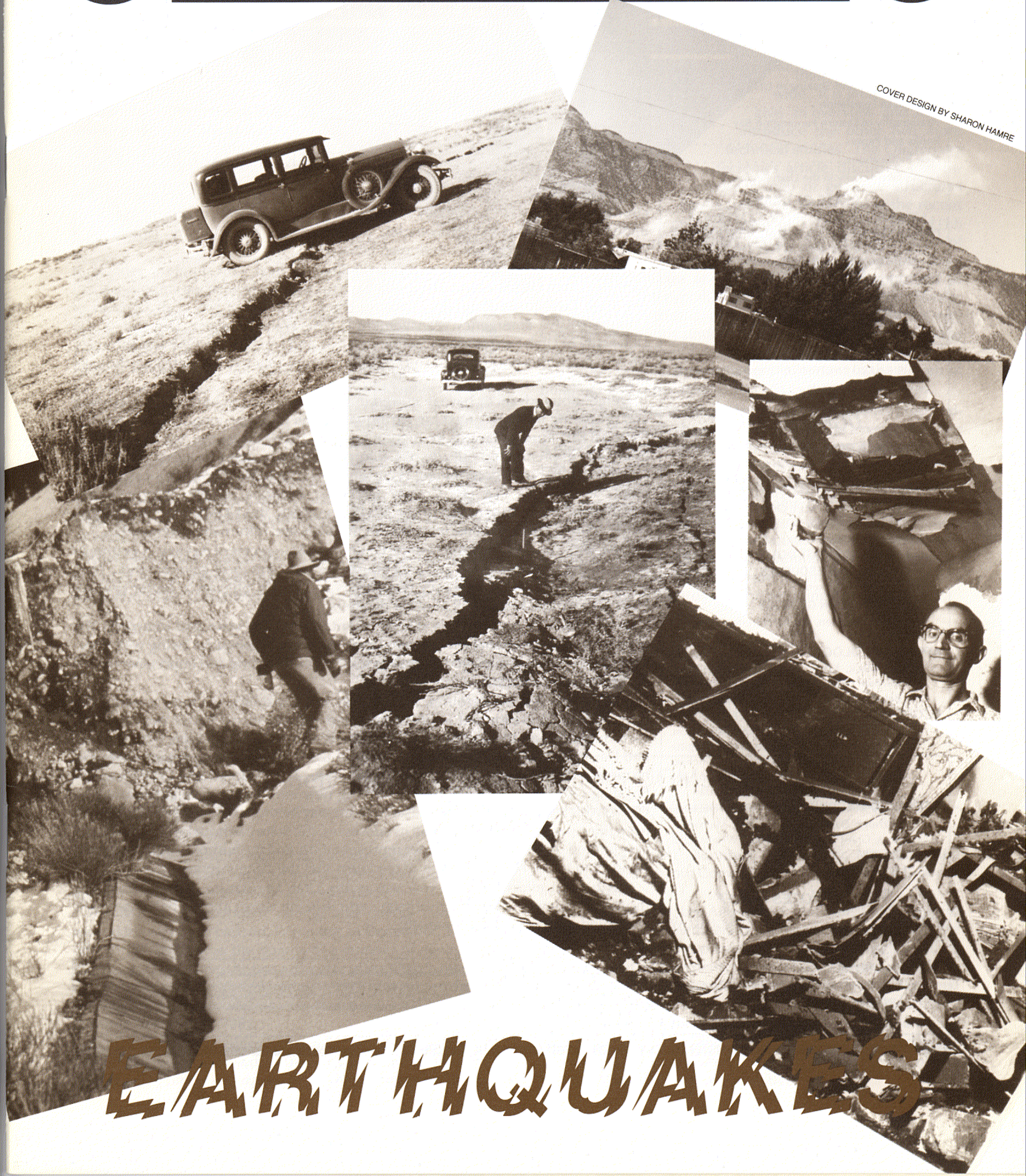
SURVEY NOTES

VOLUME 24, NUMBER 3, 1991

UTAH GEOLOGICAL AND MINERAL SURVEY

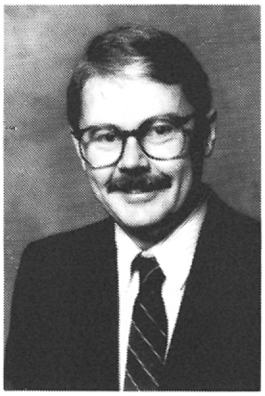
COVER DESIGN BY SHARON HAMRE



EARTHQUAKES

TABLE OF CONTENTS

**Cover Photo Captions Page 29.*



THE DIRECTOR'S PERSPECTIVE *by M. Lee Allison*

UTAH'S STATE EARTHQUAKE PROGRAM

Utah has one of the most innovative and aggressive earthquake programs in the country. However, it is essentially an ad hoc program consisting of dozens of actions undertaken by government agencies, public groups, and industry, largely on a volunteer basis and often on their own initiative.

Three of us who have major responsibilities to deal with different aspects of earthquakes in Utah meet on a frequent basis to coordinate what we ambitiously call the State Earthquake Program. Lorayne Frank, Director of the Utah Division of Comprehensive Emergency Management (CEM), Walter Arabasz, Director of the University of Utah Seismograph Stations (UUSS), and I met in late 1989 and agreed to work to promote a coordinated and comprensive approach to the state's earthquake needs.

Tremendous advances have occurred in the past decade in better understanding and preparing for Utah's next big earthquake. The five-year-long federally funded National Earthquake Hazards Reduction Program (NEHRP) was the first time such an effort was implemented outside of California. The successes in locating fault and liquefaction hazards, determining recurrence intervals, and involving local governments in activites like the County Geologist Program, greatly improved our capabilities. As an outgrowth of the NEHRP program, the UGMS now has a larger, better trained cadre of geoscientists with the skills and information we need.

CEM, with support from the Federal Emergency Management Agency, is getting in place all the response plans and procedures for state and local governments. They work with engineers, emergency responders and public officials to better prepare Utah for earthquakes as well as other disasters.

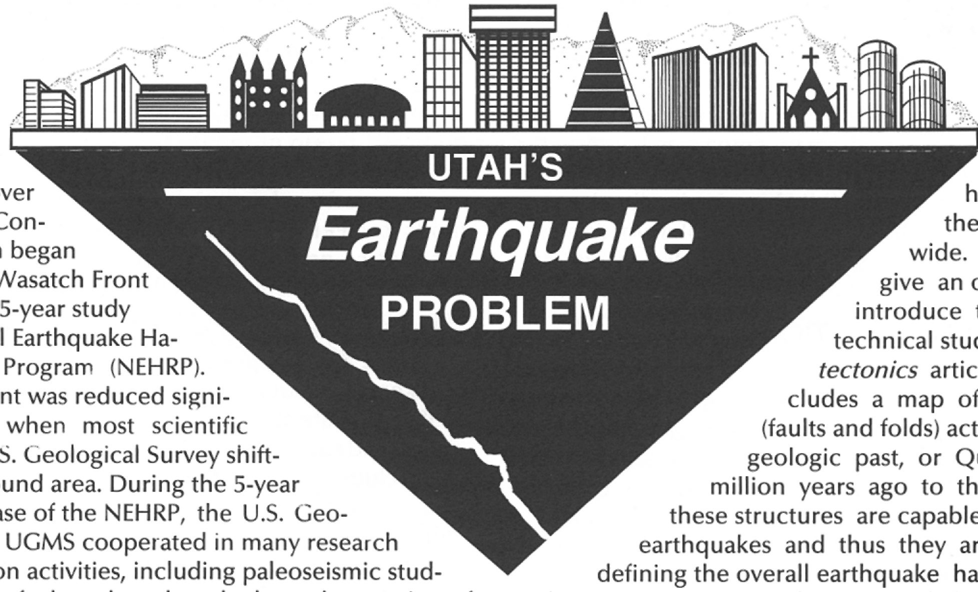
UUSS monitors and records seismic events across the state and interprets the results. A recent national review panel gave them high ratings for being well operated and excellently managed, as well as for their outstanding and impressive record of reports and publications (see p. 18).

Armed with this background, knowledge, and capability, we have entered the public arena to create and improve laws and regulations to better deal with the earthquake threat. In four counties along the Wasatch Front (Salt Lake, Utah, Weber, and Davis), detailed hazards maps are now in use by the planning departments and hazards ordinances are passed or being drafted. The International Conference of Building Officials (ICBO) will be considering new information brought forward by UGMS which indicates that the Wasatch Front may belong in UBC seismic zone 4, up from the current zone 3. But for all its successes, the State Earthquake Program is still very limited. It needs much broader representation, and the authority and funding to bring Utah to the necessary state of readiness that the danger requires.

Our biggest effort this past year was in the Utah Legislature. After a long and thorough review (see Gary Christenson's article in this issue), about a half dozen bills were filed. Not one of them passed.

(continued on page 25)...

Survey Notes *is published quarterly by* **Utah Geological and Mineral Survey,** *606 Black Hawk Way, Salt Lake City, Utah 84108 (801) 581-6831. The UGMS inventories the geologic resources of the state, identifies its geologic hazards, disseminates information concerning Utah's geology, and advises policymakers on geologic issues. The UGMS is a division of the Department of Natural Resources. Single copies of Survey Notes are distributed free of charge to residents within the United States and Canada. Reproduction is encouraged with recognition of source.*



Much attention has been paid to the earthquake problem in Utah over the past 10 years. Concentrated research began in 1983 when the Wasatch Front was targeted for a 5-year study under the National Earthquake Hazards Reduction Program (NEHRP). Federal involvement was reduced significantly in 1988, when most scientific research by the U.S. Geological Survey shifted to the Puget Sound area. During the 5-year Wasatch Front phase of the NEHRP, the U.S. Geological Survey and UGMS cooperated in many research and implementation activities, including paleoseismic studies of the Wasatch fault and earthquake-hazards mapping of Weber, Davis, Salt Lake, and Utah Counties under the Wasatch Front County Geologist Program. Following the reduction in Federal involvement, the State of Utah and specifically the UGMS has continued research and hazard-identification efforts. Whereas the NEHRP concentrated on the Wasatch Front, the UGMS has extended studies to include the entire state. We are now nearing completion of three of these statewide studies: 1) *Earthquake hazards map of Utah,* by Gary E. Christenson, 2) *Quaternary tectonics of Utah,* by Suzanne Hecker, and 3) *Earthquake ground shaking in Utah,* by Susan S. Olig. The completed reports and maps should be published and available in late 1991 or early 1992.

Brief, simplified summaries of each of these studies are included in the following pages, beginning with *Earthquake hazards of Utah.* This study is designed to give a "translated" or less technical summary of the various earthquake hazards and to show their distribution statewide. It is included here to give an overview and also to introduce the other two more technical studies. The *Quaternary tectonics* article discusses and includes a map of geologic structures (faults and folds) active during the recent geologic past, or Quaternary Period (1.6 million years ago to the present). Many of these structures are capable of generating large earthquakes and thus they are very important in defining the overall earthquake hazard in Utah. Finally, the report on *Earthquake ground shaking* addresses this very complex and poorly understood hazard, well documented as the most damaging of the many earthquake hazards. Information on ground shaking is very important in the design of buildings and other structures such as dams and bridges.

Considerable long-range planning and emergency preparedness activity has also been undertaken and, as a result, the state is now much better prepared for a damaging earthquake than it was in 1980. Of course, there is still much to be done, and an important step is to see that the information now available is used in public policy decisions. Some of the activities on this front are summarized in the article on earthquake legislation. Although it is important that earthquake research and identification of earthquake hazards continue, the State now has sufficient information to implement some key public policies to reduce these hazards and the resulting potential losses.

Bennett and Francis Resign from UGMS Board

Joseph Bennett and Gregory Francis have recently resigned from the UGMS Board because each has relocated out of state and felt unable to continue to serve effectively.

Bennett, an independent mining and energy consultant, moved his offices to Jackson, Wyoming, in December, 1990. In addition to serving on the boards of a number of mining and investment companies, he was a director of the Utah Symphony and a trustee of Holy Cross Hospital. In 1977 he was president of the Utah Mining Association. He had been a UGMS board member since March 1983.

Francis, formerly Western Division Exploration Manager with Celsius Energy, was moved to Denver when Celsius closed its Salt Lake City office. His experience includes stints with Celsius' affiliates and parent Mountain Fuel Supply, Mountain Fuel Resources, and Wexpro Company. He joined the UGMS board in June 1986.

State Geologist M. Lee Allison said "Both Joe and Greg were active, enthusiastic members of the board who supported the goals of the UGMS and provided invaluable counsel. It will be difficult to find replacements for them but fortunately both have offered to act as advisors and sounding boards when we need them. We wish them the best of luck in their new locations."

Nominees for the mining industry position on the board have been submitted to the Governor and are being reviewed by the Lieutenant Governor's office. Nominations for the petroleum position have not yet been submitted.

Earthquake Hazards of Utah

by
Gary E. Christenson

INTRODUCTION

Since the first reported Utah earthquake in 1853, approximately 700 earthquakes large enough to be felt have occurred in the state (Susan J. Nava, University of Utah Seismograph Stations, oral communication, August 1, 1990). The largest events were either prior to major development or in sparsely populated areas, and earthquake losses to date have not been great. The most damaging earthquake in Utah's history occurred in 1962 (M_L 5.7) near Richmond (Cache Valley), Utah. Over three-fourths of the houses in Richmond were damaged and mudslides and rock falls closed highways and canals. Structural damage occurred in several large buildings in Richmond and Logan, and at least one building became unsafe to occupy and had to be demolished (figure 1). The total estimated loss was about $1 million (Lander and Cloud, 1964). Elsewhere in the urbanized Wasatch Front area, eight earthquakes have caused damage (Rogers and others, 1976). This damage has consisted chiefly of cracked walls, fallen plaster (see photo on cover), toppled chimneys, and broken windows, although during the 1934 Hansel Valley earthquake, two adjacent tall buildings in downtown Salt Lake City swayed sufficiently to make contact, and the statues atop the City-County Building and Salt Lake Mormon Temple were twisted or moved out of line (Rogers and others, 1976; Oaks, 1987).

Although Utah, particularly the Wasatch Front area, has not experienced a magnitude 7.0 to 7.5 earthquake in historical time, geologic studies indicate that they have occurred repeatedly in the past and will likely occur again (for example, Schwartz and Coppersmith, 1984; Machette and others, 1987; Hecker, this issue). Loss estimates by Algermissen and others (1988) indicate that such an earthquake in the Salt Lake City area could cause over $5.5 billion in damage to buildings alone, not including damage to other kinds of structures and facilities, and other indirect financial losses. Projected life-loss and injury studies by Rogers and others (1976), which are now out of date and probably low, indicate that under the worst conditions (excepting dam failure), 2300 people may die and 9000 suffer injuries requiring medical treatment. As many as 30,000 people may be homeless and require temporary shelter, a problem of particular concern with a winter earthquake.

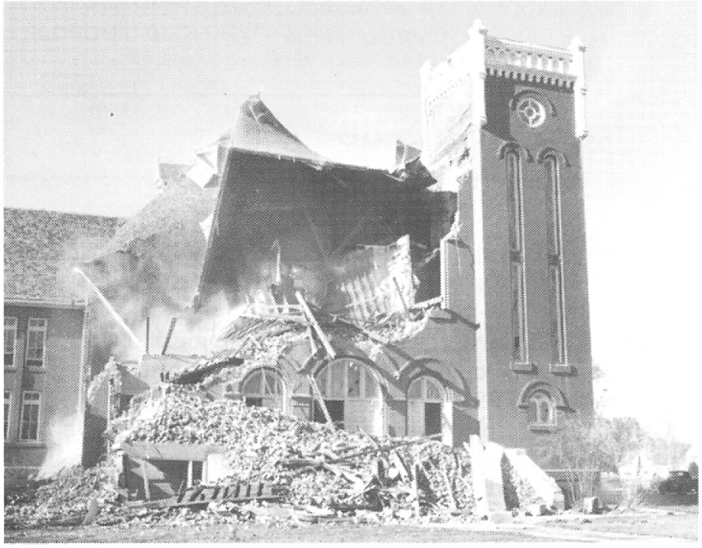


Figure 1. Demolition of the Benson Stake Tabernacle in Richmond which was damaged beyond repair by the 1962 Richmond earthquake. Photo by Ariel D. Benson, Richmond, Utah.

EARTHQUAKE OCCURRENCE

Information regarding earthquake size and location is obtained both from historical (including instrumental) records and from the geologic record. Historical records are collected and compiled by the University of Utah Seismograph Stations (UUSS; Arabasz and others, 1979). The UUSS began operating a network of seismographs in 1962 to systematically record seismic events in the Utah area. Prior to 1962, records were chiefly from newspaper accounts and other reports where the effects were felt. Figure 2 is a plot of epicenters of the largest reported earthquakes from 1850 to December, 1990 (Arabasz and Smith, 1979; University Seismograph Stations unpublished data).

Most earthquakes in Utah occur in a zone trending north-south through the center of the state called the Intermountain seismic belt (ISB; Smith and Sbar, 1974) (figure 2). The state's larger historical earthquakes have occurred in the ISB, including the two largest (1934 Hansel Valley, M_L 6.6; 1901 Richfield, magnitude 6.5) and the most damaging (1962 Richmond, M_L 5.7) (Arabasz and Smith, 1979). Several damaging earthquakes felt in Utah have occurred in parts of the ISB in adjacent states. These events include the 1959 Hebgen Lake, Montana (M_S 7.5); 1975 Pocatello Valley, Idaho (M_L 6.0); and 1983 Borah Peak, Idaho (M_S 7.3) earthquakes. Few earthquakes greater than magnitude 4.0 have occurred outside the ISB in Utah (figure 2). The largest (San Rafael Swell earthquake, M_L 5.3) occurred in August, 1988, east of Castledale.

Earthquakes smaller than magnitude 6.5 generally do not cause noticeable changes in the ground surface and thus are rarely reflected in the geologic record. Because of this, historical seismicity is the only source of data with which to estimate the probability of occurrence of these earthquakes. However, for earthquakes greater than magnitude 6.5, the fault rupture commonly propagates to the surface. These surface ruptures may remain evident for many thousands of years and can be identified and studied by geologists. The chronology of surface-faulting earthquakes can be determined from detailed fault-zone mapping and logging of trench excavations. Preliminary estimates based on such studies on the Wasatch fault, considered to be the most active fault in Utah, indicate that on the six active central segments of the fault, earthquakes of magnitude 7.0 to 7.5 have occurred on average every 400 years (over the last 6000 years) (Machette and others, in press). Based on these data, and considering different models of earthquake occurrence, it is estimated that there is anywhere from a 12 to a 24 percent probability (Nishenko and Schwartz, 1990), or about a one in nine to one in four chance, of such an earthquake occurring along the Wasatch fault in 50 years. There are many other potentially active faults in Utah (Hecker, this issue), and thus the probability is greater of such an earthquake in 50 years somewhere in the entire state.

EARTHQUAKE HAZARDS

Earthquake hazards are geologic phenomena that occur during an earthquake that have the potential to cause damage or life loss. The principal earthquake hazards are ground shaking, surface fault rupture, tectonic subsidence, liquefaction and related ground failure, slope failure, and flooding. In dealing with these hazards, it is important to know where they occur (location), how often they occur (commonly expressed as the probability of occurrence or relative likelihood), and what happens when they occur (consequences or severity) (Kockelman, 1990).

GROUND SHAKING

Ground shaking is generally the most damaging and widespread hazard associated with earthquakes. Ground shaking may damage structures as they are subjected to forces, particularly horizontal motions, that they were not designed to withstand. Damage or collapse of buildings and other man-made structures due to ground shaking is a leading cause of death and injury during an earthquake. In addition to structural damage, building contents may be shaken loose, tipped, or otherwise damaged.

TABLE 1.
Modified Mercalli intensity scale of 1931 (simplified from Wood and Neumann, 1931).

I-II	Felt only by a few persons at rest.
III	Felt quite noticeably indoors.
IV	Dishes, windows, doors disturbed; walls make cracking sound.
V	Some dishes, windows broken; a few instances of cracked plaster.
VI	A few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures.
IX	Damage considerable in specially designed structures; great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed.
XI	Few, if any, masonry structures remain standing. Bridges destroyed.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed.

There are many ways to measure and depict ground shaking. The Modified Mercalli intensity (MMI) scale is commonly used to rank the effects of an earthquake at a specific location. It is a subjective scale based on observed damage and other physical effects caused by ground shaking (table 1). For individual earthquakes, a common method of depicting variations in levels of ground shaking is to construct "isoseismal" maps showing the distribution of MMIs experienced at various reporting sites in the felt area (figure 3). MMI VI is generally considered to be the threshold of damaging ground motion. Figure 4 shows the maximum reported MMIs (MMI VI and greater) at various reporting stations (post offices) in Utah from 1853 to 1990. The figure illustrates the greater ground-shaking hazard in the ISB where most of the larger MMIs have been reported. The hazard is significantly less both east and west of the ISB. Figure 4 does not reflect the greatest MMI that may occur at any site in the future, and an MMI several increments larger is possible. For example, studies in the Salt Lake City area by Algermissen and others (1988) and Emmi (1990) indicate possible MMIs as high as X and XI, respectively, although historically the largest MMI has been VII or VIII (Oaks, 1987; Hopper, 1988).

Another method of characterizing ground shaking is to measure, with special seismographs, the actual ground displacement, velocity, and acceleration at a site due to seismic waves of various types and frequencies. In the absence of such measurements, theoretical studies can be performed to estimate these ground-shaking parameters, although these estimates may have large uncertainties associated with them. This type of ground-shaking information is particularly important to engineers in designing and constructing buildings and other structures. A discussion of such ground-shaking information and its implications for buildings in Utah is summarized in the article by Susan Olig.

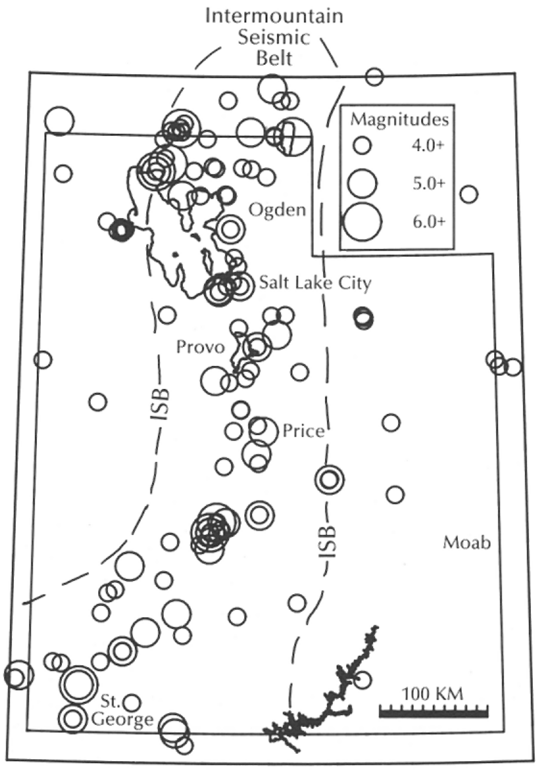


Figure 2. Historical earthquakes of magnitude four or greater in the Utah area from 1850 to October, 1990 (from the University of Utah Seismograph Stations catalog). General outline of the Intermountain seismic belt (ISB) from Arabasz and others (1987).

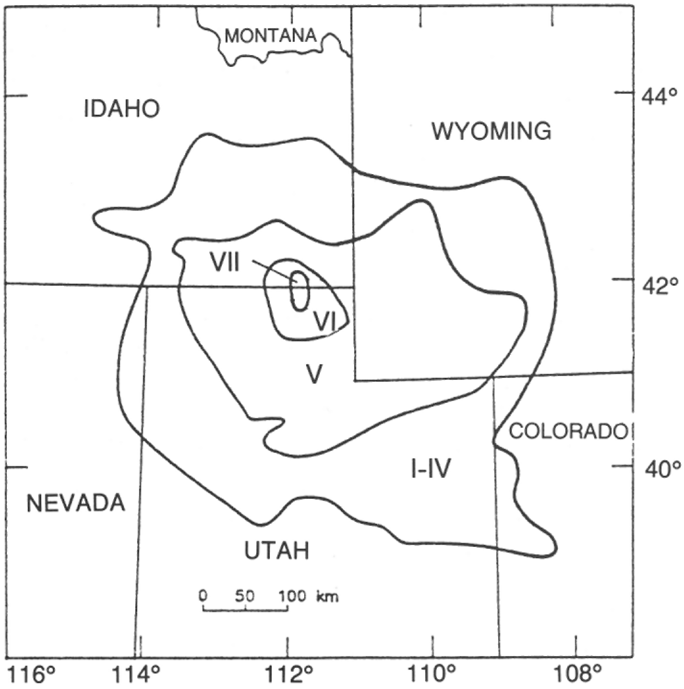


Figure 3. Isoseismal map of the 1962 Richmond (Cache Valley) earthquake (M_L 5.7) (Lander and Cloud, 1964; Hopper, 1988).

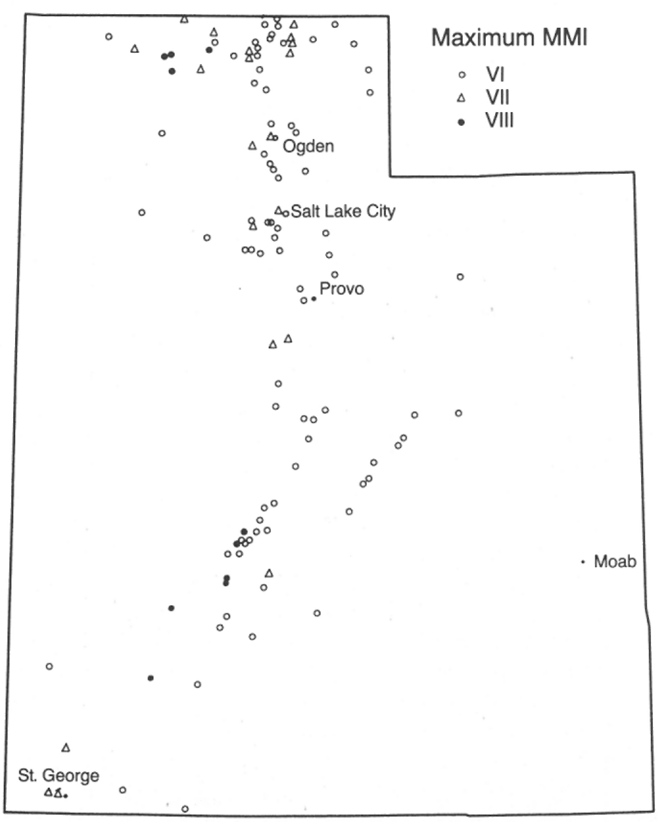


Figure 4. Maximum Modified Mercalli intensities (MMI VI and greater) for various reporting stations (post offices) for historical earthquakes in Utah from 1853 to 1990. Data are from the U.S. Geological Survey National Earthquake Information Center, Golden, Colorado.

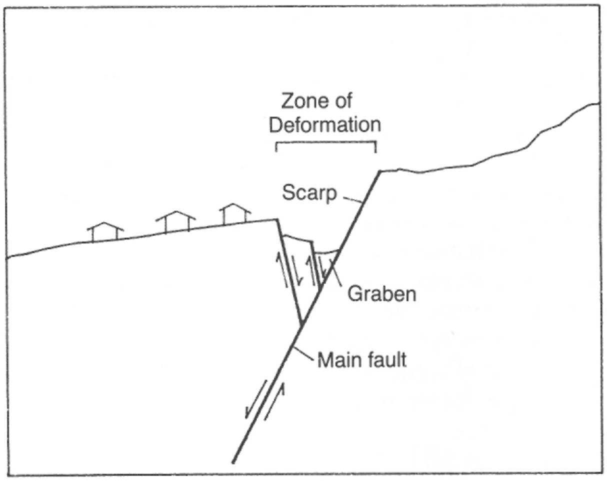


Figure 5. Diagrammatic cross section of a typical surface fault rupture zone associated with normal faulting (modified from Robison, 1990).

SURFACE FAULT RUPTURE

During earthquakes greater than about magnitude 6.5, the fault rupture at depth causing the earthquake may propagate to the surface. This has occurred only once in Utah during historical time, and that was during the 1934 Hansel Valley earthquake (M_L 6.6) (see photo on cover). Surface faulting presents several hazards to people and their structures. It can crack foundations, sever lifelines and transportation corridors, destroy buildings, and threaten lives. Surface displacement commonly does not occur along a single discrete plane but may occur over a zone hundreds of meters wide called the zone of deformation (figure 5). Features common in this zone include tilted or warped beds and grabens (downdropped blocks between faults with opposite dip directions) (figure 5). While most damage may occur along the main fault, lesser faults and local tilting in the zone of deformation can also cause damage. The type of scarp and zone of deformation formed during a single earthquake is illustrated in figure 6. Repeated surface faulting over many thousands of years may form high scarps, deep grabens, and wide zones of deformation as shown in figure 7 near Salt Lake City.

Figure 6. Fault scarp and graben formed during the 1983 Borah Peak earthquake in Idaho.

The potential for surface fault rupture is greatest along young Quaternary faults. A compilation of all such mapped faults is shown in a map by Suzanne Hecker in this issue. She has categorized these faults according to the time of last movement, or time of the most recent surface-faulting earthquake. The surface-fault-rupture hazard (that is, the relative likelihood of surface faulting in the future) in part depends on the time of last movement, but it also depends on the average recurrence interval between earthquakes during late Quaternary time. Available data on both time of last movement and average recurrence for Quaternary faults in Utah have been compiled by Hecker (in preparation) and were used here to estimate relative surface rupture hazards.

The faults with the greatest surface rupture hazard are those which have been active repeatedly during Holocene time (10,000 years ago to the present) and have an average recurrence interval of less than 10,000 years. Most are in northern Utah, and they include the central segment(s) of the Wasatch and East Cache faults, and the West Valley, Hansel Valley, eastern Bear Lake, Bear River, Strawberry, and Joes Valley faults (figure 8). Details of the Holocene rupture history for most of these faults is discussed further in Suzanne Hecker's article. The central Wasatch fault segments are considered to be the most active in the state (Hecker, in preparation) and thus have the highest surface-rupture hazard. Although faults with a high potential for surface rupture are also found in the Needles area of Canyonlands National Park, this activity is probably related to salt flowage and dissolution and gravity sliding, not to earthquake-generating tectonic forces (see Hecker, this issue). Likewise, there is some question whether the West Valley and Joes Valley faults in northern Utah are capable of generating large earthquakes; the repeated surface ruptures on these faults may be the result of other causes.

Only those faults which have been shown, through detailed study, to have been active repeatedly during Holocene time are differentiated in figure 8. Other faults shown in figure 8 have an average recurrence interval of generally greater than 10,000 years, and thus have relatively low to moderate surface rupture hazard. However, data are lacking on many of these faults and it is possible that further study may indicate a higher hazard.

Figure 7. *Multiple-event fault scarp and graben along the Wasatch fault at the mouth of Little Cottonwood Canyon near Salt Lake City.*

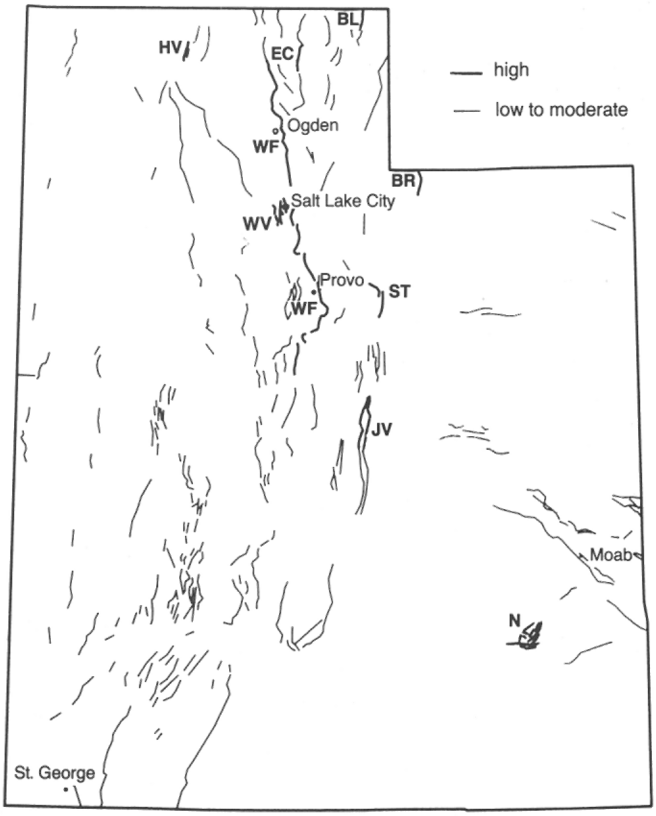


Figure 8. *Relative surface rupture hazard for Quaternary-age faults in Utah (BL, eastern Bear Lake; BR, Bear River; EC, East Cache; HV, Hansel Valley; JV, Joes Valley; N, Needles; ST, Strawberry; WF, Wasatch; WV-West Valley).*

TECTONIC SUBSIDENCE

A hazard related to surface faulting is tectonic subsidence. Along many faults, subsidence due to repeated surface-faulting earthquakes over many thousands of years has lowered the region on the downdropped side of the fault such that it is presently a basin. The amount of subsidence during an individual earthquake is directly related to the amount of displacement on the fault. It is generally greatest at the fault and gradually diminishes with distance away from it. Maximum subsidence of about 1.2 m (4 ft) occurred near the fault in the 1983 Borah Peak, Idaho earthquake, gradually diminishing to zero about 19 km (12 mi) away (Stein and Barrientos, 1985). Subsidence of up to 6 m (20 ft) during the 1959 Hebgen Lake, Montana earthquake caused the lake to shift northward and flood the north shore nearest the fault (Myers and Hamilton, 1964). Flooding may also occur in areas of shallow ground water where the ground surface is dropped below the water table. Tilting due to tectonic subsidence is permanent and, in addition to causing flooding, can alter stream courses and lessen or reverse gradients in sewer lines, canals, or other gravity-dependent systems (Keaton, 1987).

Significant tectonic subsidence occurs principally during earthquakes accompanied by surface faulting and thus has the same probability of occurrence as surface faulting along any given fault. The maximum amount of subsidence will generally depend on the amount of fault displacement, but the effects and potential for damage depend on the depth to ground water and presence of surface water (lakes, streams) on the downdropped block. The hazard is particularly important along the Wasatch Front where Great Salt Lake and Utah Lake may shift eastward and flood large urban areas during an earthquake on the Wasatch fault (Smith and Richins, 1984; Keaton, 1987).

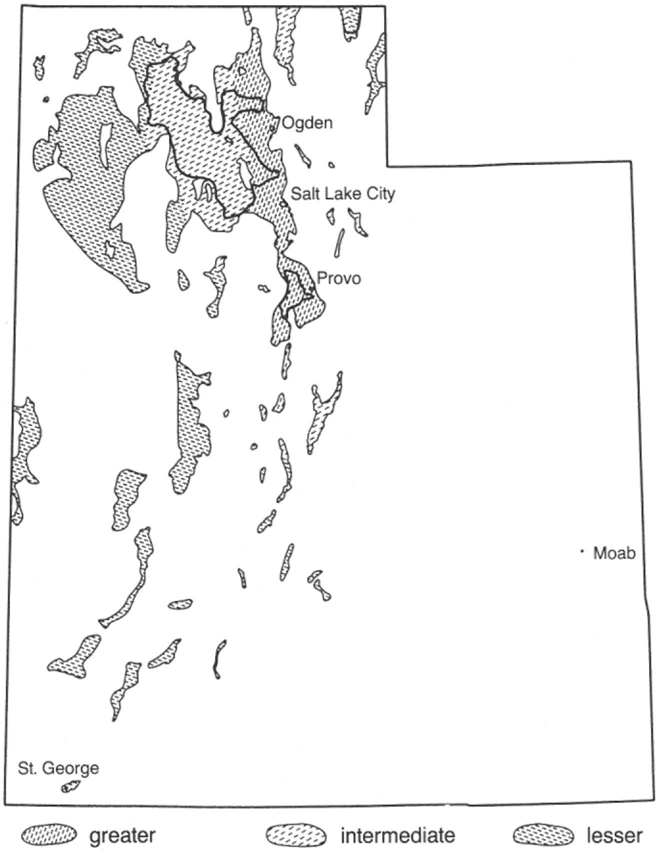


Figure 9. *Relative liquefaction hazard in Utah.*

LIQUEFACTION AND RELATED GROUND FAILURE

Ground shaking may have particularly adverse effects under certain soil and ground-water conditions, and one of these effects is called soil liquefaction. It occurs principally in saturated, cohesionless sand and silt as ground shaking causes a temporary "quicksand" condition where the soil loses its ability to support loads such as buildings or overlying soil layers. In general, liquefaction only occurs during earthquakes of M_L 5.0 (maximum MMI VI-VII) or larger (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977; National Research Council, 1985). Liquefaction may occur repeatedly in the same area, either from large aftershocks following a main shock or from unrelated earthquakes.

When a soil layer liquefies, ground failure may occur by several mechanisms, depending on the slope of the ground surface. If the ground is flat, liquefaction may cause ground cracking and differential settlement, and heavy structures may settle, crack, or tip. If the ground slopes, lateral spreads (small downslope displacements of generally intact soil slabs) and flow failures (large, rapid debris-flow-like failures) may occur (Youd, 1978). Lateral spreading is the most common type of liquefaction-induced ground failure and has caused more damage than any other type of ground failure during earthquakes (Keefer, 1984; Earthquake Engineering Research Institute, 1986).

Relative liquefaction hazards in Utah are shown in figure 9. This analysis considers chiefly ground-water conditions and the potential for strong earthquake ground shaking and liquefaction-induced ground failure, and it is based principally on data and maps by Mabey and Youd (1989) and Hecker and others (1988). The analysis assumes that susceptible soil is present, although some modifications have been made where susceptible soil has been shown by Anderson and others (1982, 1986a, 1986b, 1990a, 1990b) to be absent.

The area of greater hazard shown in figure 9 is along the Wasatch Front where shallow ground water and a higher probability of strong ground shaking combine to cause the greatest likelihood for damaging liquefaction. In areas of intermediate hazard, generally in northern Utah surrounding the Wasatch Front, liquefaction may occur but is less likely and the resulting ground failure would probably be less damaging. The areas of lesser hazard, generally in the southern ISB and western Utah, are all those additional areas in the state where liquefaction is possible, but not likely, and if it were to occur would probably not be very damaging. The remainder of the state is generally free from liquefaction hazards because of the lack of soil and shallow ground water, and the lower earthquake probability.

SLOPE FAILURE

Slope failures (slumps, slides, and rock falls) other than those related to liquefaction also commonly occur during earthquakes. Keefer (1984) studied the occurrence of slope failures in 40 historical earthquakes worldwide, and he determined that the minimum Richter magnitude needed to initiate them is about M_L 4.0. At this magnitude, some types of failures in both soil and rock, mainly rock falls, may occur in the epicentral area. The maximum distance from the epicenter where slope failures can occur is directly dependent on earthquake magnitude, although other factors cause variations locally. Figure 10 is a graph of the maximum distances of various types of slope failures from the epicenters of earthquakes studied by Keefer (1984). He subdivided slope failures into three categories: 1) disrupted slides and falls (chiefly rock falls), 2) coherent slides (slumps and earth flows), and 3) lateral spreads and flows (see liquefaction discussion above).

Rock falls are the most common slope failure during earthquakes (Keefer, 1984) and may occur up to 280 km (175 mi) in any direction from a magnitude 7.5 earthquake, the maximum magnitude earthquake expected in the Utah region. For these larger earthquakes, there is little difference in the maximum distance from the epicenter for the various failure types (figure 10). Thus, such an earthquake in the Salt Lake City area could generate slope failures over most of northern Utah, although they would be larger and more numerous nearer the epicenter. For moderate earthquakes, the maximum distances for various types of slope-failure occurrence is more variable. For example, disrupted falls and slides may occur up to 80 km (50 mi) from the epicenter of a M_L 6.0 earthquake, whereas coherent slides may only be found within 40 km (25 mi) of the epicenter (figure 10). Rock falls and rock slides were common in the epicentral area during the 1983 Borah Peak, Idaho earth-downdropped block. The hazard is particularly important along the Wasatch Front where Great Salt Lake and Utah Lake may shift eastward and flood large urban areas during an earthquake on the Wasatch fault (Smith and Richins, 1984; Keaton, 1987).

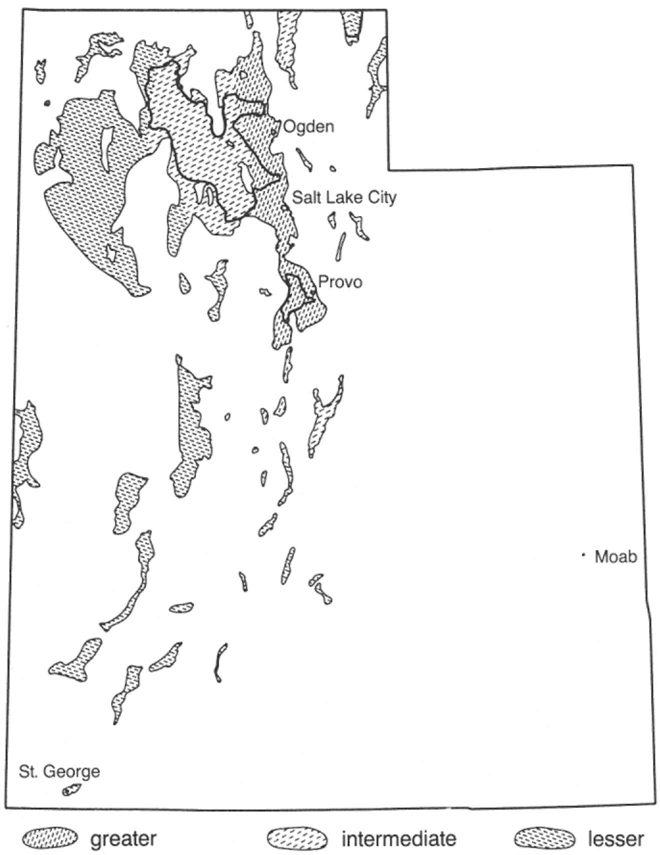


Figure 9. *Relative liquefaction hazard in Utah.*

LIQUEFACTION AND RELATED GROUND FAILURE

Ground shaking may have particularly adverse effects under certain soil and ground-water conditions, and one of these effects is called soil liquefaction. It occurs principally in saturated, cohesionless sand and silt as ground shaking causes a temporary "quicksand" condition where the soil loses its ability to support loads such as buildings or overlying soil layers. In general, liquefaction only occurs during earthquakes of M_L 5.0 (maximum MMI VI-VII) or larger (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977; National Research Council, 1985). Liquefaction may occur repeatedly in the same area, either from large aftershocks following a main shock or from unrelated earthquakes.

When a soil layer liquefies, ground failure may occur by several mechanisms, depending on the slope of the ground surface. If the ground is flat, liquefaction may cause ground cracking and differential settlement, and heavy structures may settle, crack, or tip. If the ground slopes, lateral spreads (small downslope displacements of generally intact soil slabs) and flow failures (large, rapid debris-flow-like failures) may occur (Youd, 1978). Lateral spreading is the most common type of liquefaction-induced ground failure and has caused more damage than any other type of ground failure during earthquakes (Keefer, 1984; Earthquake Engineering Research Institute, 1986).

Relative liquefaction hazards in Utah are shown in figure 9. This analysis considers chiefly ground-water conditions and the potential for strong earthquake ground shaking and liquefaction-induced ground failure, and it is based principally on data and maps by Mabey and Youd (1989) and Hecker and others (1988). The analysis assumes that susceptible soil is present, although some modifications have been made where susceptible soil has been shown by Anderson and others (1982, 1986a, 1986b, 1990a, 1990b) to be absent.

The area of greater hazard shown in figure 9 is along the Wasatch Front where shallow ground water and a higher probability of strong ground shaking combine to cause the greatest likelihood for damaging liquefaction. In areas of intermediate hazard, generally in northern Utah surrounding the Wasatch Front, liquefaction may occur but is less likely and the resulting ground failure would probably be less damaging. The areas of lesser hazard, generally in the southern ISB and western Utah, are all those additional areas in the state where liquefaction is possible, but not likely, and if it were to occur would probably not be very damaging. The remainder of the state is generally free from liquefaction hazards because of the lack of soil and shallow ground water, and the lower earthquake probability.

SLOPE FAILURE

Slope failures (slumps, slides, and rock falls) other than those related to liquefaction also commonly occur during earthquakes. Keefer (1984) studied the occurrence of slope failures in 40 historical earthquakes worldwide, and he determined that the minimum Richter magnitude needed to initiate them is about M_L 4.0. At this magnitude, some types of failures in both soil and rock, mainly rock falls, may occur in the epicentral area. The maximum distance from the epicenter where slope failures can occur is directly dependent on earthquake magnitude, although other factors cause variations locally. Figure 10 is a graph of the maximum distances of various types of slope failures from the epicenters of earthquakes studied by Keefer (1984). He subdivided slope failures into three categories: 1) disrupted slides and falls (chiefly rock falls), 2) coherent slides (slumps and earth flows), and 3) lateral spreads and flows (see liquefaction discussion above).

Rock falls are the most common slope failure during earthquakes (Keefer, 1984) and may occur up to 280 km (175 mi) in any direction from a magnitude 7.5 earthquake, the maximum magnitude earthquake expected in the Utah region. For these larger earthquakes, there is little difference in the maximum distance from the epicenter for the various failure types (figure 10). Thus, such an earthquake in the Salt Lake City area could generate slope failures over most of northern Utah, although they would be larger and more numerous nearer the epicenter. For moderate earthquakes, the maximum distances for various types of slope-failure occurrence is more variable. For example, disrupted falls and slides may occur up to 80 km (50 mi) from the epicenter of a M_L 6.0 earthquake, whereas coherent slides may only be found within 40 km (25 mi) of the epicenter (figure 10). Rock falls and rock slides were common in the epicentral area during the 1983 Borah Peak, Idaho earth-

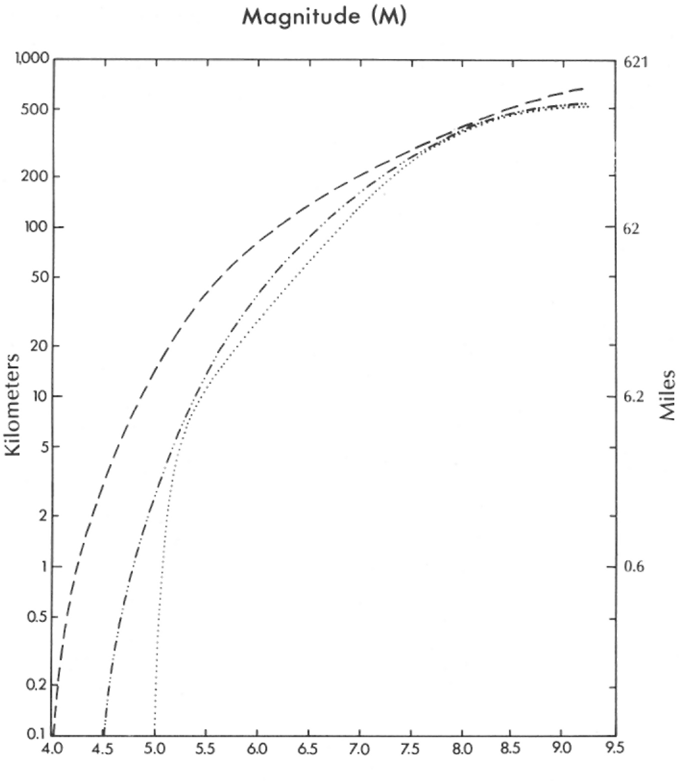


Figure 10. *Maximum distance from epicenter to landslides for earthquakes of different magnitudes; dashed line is upper boundary for disrupted falls and slides, dash-double-dot line is upper boundary for coherent slides, and dotted line is upper boundary for lateral spreads and flows (Keefer, 1984).*

quake, and houses and cars were damaged by rock falls in Challis about 56 km (35 mi) from the epicenter. Possibly hundreds of rock falls occurred within 40 km (25 mi) of the 1988 San Rafael Swell earthquake (M_L 5.3) near Castledale, and isolated rock falls were reported up to 113 km (70 mi) from the epicenter (see photo on cover; Case, 1988).

The Utah Geological and Mineral Survey has produced a landslide map of Utah (see Survey Notes, Winter, 1989), soon to be published at a scale of 1:500,000 (Harty, in press). This map gives an indication of where potentially unstable slopes are found, and where slope failures (other than rock falls) have occurred in the past and thus are likely to occur in the future, whether earthquake-induced or not. The relative hazard from earthquake-induced slope failures is greatest for unstable slopes in the ISB where larger earthquakes are most common.

OTHER HAZARDS

Earthquakes may also cause a variety of other less common, but potentially damaging, geologic effects. Among these are snow avalanches, ground failure due to loss of strength in sensitive clays, subsidence caused by vibratory settlement in granular soils and fill, and flooding. Flooding during earthquakes is commonly a secondary effect of other hazards, such as surface faulting, tectonic subsidence, and ground shaking, and may include dam failures, seiches (earthquake-induced "sloshing" in lakes and reservoirs), surface drainage disruptions, and increased ground-water discharge.

EARTHQUAKE HAZARD REDUCTION

Although earthquakes cannot be prevented, much can be done to lessen their impacts and protect people and property from unnecessary risk. Detailed studies in Utah, particularly over the past 5 to 10 years, have greatly advanced our knowledge of earthquake hazards and enabled the delineation of areas of greatest hazards and identification of steps that can be taken to reduce these hazards (Arabasz, 1990). Earthquake hazards are many and varied, and so too are the techniques used to reduce their impacts. However, most techniques are generally applied through: 1) building codes, and 2) land-use planning and zoning ordinances.

Building codes, such as the 1988 Uniform Building Code (UBC) adopted statewide in Utah in 1989, regulate the type and quality of building construction and specifically address the earthquake ground-shaking hazard. In earthquake-prone areas, the UBC has special requirements for structural and architectural strengthening to resist the lateral forces of ground shaking. A complete discussion of Utah's building code with respect to ground shaking is included in Susan Olig's article.

In part because large-scale maps depicting ground shaking are not available for most areas, reduction of ground-shaking hazards through land-use planning is not practiced in Utah. However, research is underway which may make such planning practical in the future (Emmi, 1990; Olig, this issue). Most other earthquake hazards are more site-specific than ground shaking and can be effectively reduced through proper land-use planning, including avoiding hazards or using engineered protective measures. Land use is regulated in Utah by local governments (towns, cities, and counties) and is carried out through master plans and specific ordinances: zoning, subdivision, natural hazards, hillside, or sensitive area. The approach used by local governments varies, but the one most commonly used along the Wasatch Front is to adopt maps depicting the various hazards and to require site-specific reports for any proposed development in mapped hazard areas. These reports must delineate the hazards and recommend hazard-reduction measures. Details of the process are summarized in Christenson (1987), Gori (1990), and Lowe (1990).

Hazard-reduction measures vary greatly but include such actions as: 1) avoidance, 2) setbacks from faults and unstable slopes, 3) special foundation preparation and design, 4) engineered slope stabilization, and 5) flood proofing. The actual technique used depends on the type of structure, level of risk, severity and probability of the hazard, and economics of the project. Hazard-reduction strategies can range from the very economical (for example, geologic studies to guide land use) to the very expensive (for example, retrofitting of unreinforced masonry buildings). In all cases, the cost of the reduction measure must be weighed against the probability of hazard occurrence, the risk to lives, and the potential economic loss. Nearly all risk posed by earthquakes is through damage to and failure of engineered structures (building and bridge collapse, dam failure, and fire), and thus it is within our ability to significantly reduce that risk through proper siting and engineering practices.

REFERENCES

Algermissen, S.T., Arnold, E.P., Steinbrugge, K.V., Hopper, M.G., and Powers, P.S., 1988, Earthquake losses in central Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Volume III: U.S. Geological Survey Open-File Report 88-680, p. X-1-62.

Anderson, L.R., Keaton, J.R., Aubry, Kevin, and Ellis, S.J., 1982, Liquefaction potential map for Davis County, Utah: Utah State University Department of Civil and Environmental Engineering and Dames and Moore unpublished Final Technical Report for the U.S. Geological Survey, 50 p.

Anderson, L.R., Keaton, J.R., and Bay, J.A., 1990a, Liquefaction potential map for the northern Wasatch Front, Utah: Utah State University Department of Civil and Environmental Engineering unpublished Final Technical Report for the U.S. Geological Survey, 150 p.

Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1986a, Liquefaction potential map for Utah County, Utah: Utah State University Department of Civil and Environmental Engineering and Dames and Moore unpublished Final Technical Report for the U.S. Geological Survey, 46 p.

Anderson, L.R., Keaton, J.R., and Rice, J.D., 1990b, Liquefaction potential map for central Utah: Utah State University Department of Civil and Environmental Engineering unpublished Final Technical Report for the U.S. Geological Survey, 134 p.

Anderson, L.R., Keaton, J.R., Spitzley, J.E., and Allen, A.C., 1986b, Liquefaction potential map for Salt Lake County, Utah: Utah State University Department of Civil and Environmental Engineering and Dames and Moore unpublished Final Technical Report for the U.S. Geological Survey, 48 p.

Arabasz, W.J., editor, 1990, A guide to reducing losses from future earthquakes in Utah, "Consensus document": Unpublished report, 25 p.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1987, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume I: U.S. Geological Survey Open-File Report 87-585, p. D-1-58.

Arabasz, W.J., and Smith, R.B., 1979, Introduction: What you've always wanted to know about earthquakes in Utah, *in* Arabasz, W.J., Smith, R.B., and Richins, W.D., editors, Earthquake Studies in Utah, 1850 to 1978: University of Utah Seismograph Stations, Department of Geology and Geophysics, p. 1-14.

Case, W.F., 1988, Geologic effects of the 14 and 18 August, 1988 earthquakes in Emery County, Utah: Utah Geological and Mineral Survey, Survey Notes, v. 22, no. 1-2, p. 8-15.

Christenson, G.E., 1987, Suggested approach to geologic hazards ordinances in Utah: Utah Geological and Mineral Survey Circular 79, 16 p.

Earthquake Engineering Research Institute, 1986, Reducing earthquake hazards: Lessons learned from earthquakes: Earthquake Engineering Research Institute Publication No. 86-02, 208 p.

Emmi, P.C., 1990, A mapping of ground shaking intensities for Salt Lake County, Utah, *in* Gori, P.L., editor, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume IV: U.S. Geological Survey Open-File Report 90-225, p. EE-1-34

Gori, P.L., editor, 1990, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, Volume IV: U.S. Geological Survey Open-File Report 90-225, variously paginated.

Harty, K.M., in press, Landslide map of Utah: Utah Geological and Mineral Survey Map, scale 1:500,000.

Hecker, Suzanne, in preparation, Quaternary tectonics of Utah — with emphasis on seismic source characterization: Utah Geological and Mineral Survey Special Studies.

Hecker, Suzanne, Harty, K.M., and Christenson, G.E., 1988, Shallow ground water and related hazards in Utah: Utah Geological and Mineral Survey Map 110, scale 1:750,000.

Hopper, M.G., 1988, Isoseismals of some historical earthquakes affecting the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume III: U.S. Geological Survey Open-File Report 88-680, p. Y-1-28.

Keaton, J.R., 1987, Potential consequences of earthquake-induced regional tectonic deformation along the Wasatch Front, north-central Utah, *in* McCalpin, James, editor, Proceedings of the 23rd Annual Symposium on Engineering Geology and Soils Engineering: Utah State University, April 6-8, 1987, p. 19-34.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406-421.

Kockelman, W.J., 1990, Reducing earthquake hazards in Utah: The crucial connection between researchers and practitioners, *in* Gori, P.L., editor, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume IV: U.S. Geological Survey Open-File Report 90-225, p. AA-1-153.

Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975, Brief review of liquefaction during earthquakes in Japan: Soils and Foundations, v. 15, no. 4, p. 81-92.

——1977, History of earthquake-induced liquefaction in Japan: Japan Ministry of Construction, Public Works Research Institute Bulletin, v. 31, 26 p.

Lander, J.F., and Cloud, W.K., 1964, United States earthquakes, 1962: U.S. Coast and Geodetic Survey, 114 p.

Lowe, Mike, 1990, Geologic hazards and land-use planning: Background, explanation, and guidelines for development in Davis County in designated geologic hazards special study areas: Utah Geological and Mineral Survey Open-File Report 198, 75 p.

Mabey, M.A., and Youd, T.L., 1989, Liquefaction severity index maps of the State of Utah, *in* Watters, R.J., editor, Engineering Geology and Geotechnical Engineering: Rotterdam, A.A. Balkema, Proceedings of the 25th Annual Engineering Geology and Geotechnical Engineering Symposium, p. 305-312.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1987, Quaternary geology along the Wasatch fault zone: Segmentation, recent investigations, and preliminary conclusions, *in* Hays, W.W., and Gori, P.L., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume I: U.S. Geological Survey Open-File Report 87-585, p. A-1-72.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., in press, The Wasatch fault zone, Utah — Segmentation and history of Holocene earthquakes: Journal of Structural Geology.

Myers, W.B., and Hamilton, Warren, 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435, p. 55-98.

National Research Council, 1985, Liquefaction of soils during earthquakes: Washington, D.C., National Academy Press, 240 p.

Nishenko, S.P., and Schwartz, D.P., 1990, Preliminary estimates of large earthquake probabilities along the Wasatch fault zone, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 71, no. 43, p. 1448.

Oaks, S.D., 1987, Effects of six damaging earthquakes in Salt Lake City, Utah, *in* Hays, W.W., and Gori, P.L., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume III: U.S. Geological Survey Open-File Report 87-585, p. P-1-95.

Robison, R.M., 1990, Surface fault rupture: A guide for land-use planning, Utah and Juab Counties, Utah, *in* Gori, P.L., editor, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume IV: U.S. Geological Survey Open-File Report 90-225, p. GG-1-25

Rogers, A.M. and others, 1976, A study of earthquake losses in the Salt Lake City, Utah area: U.S. Geological Survey Open-File Report 76-89, 357 p.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch Front: Paradigm and paradox, *in* Hays, W.W., and Gori, P.L., editors, A Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 73-112.

Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain seismic belt: Geological Society of America Bulletin, v. 85, p. 1205-1218.

Stein, R.S., and Barrientos, S.E., 1985, The 1983 Borah Peak, Idaho earthquake; geodetic evidence for deep rupture on a planar fault, *in* Stein, R.S., and Bucknam, R.C., editors, Proceedings of Workshop XXVIII on the Borah Peak Idaho Earthquake, Volume A: U.S. Geological Survey Open-File Report 85-290, p. 459-484.

Wood, H.O., and Neumann, R., 1931, Modified Mercalli intensity scale of 1931: Bulletin of the Seismological Society of America, v. 21, no. 1, p. 39-43.

Youd, T.L., 1977, Discussion of "Brief review of liquefaction during earthquakes in Japan", by Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975: Soils and Foundations, v. 17, no. 1, p. 82-85.

——1978, Major cause of earthquake damage is ground failure: American Society of Civil Engineers, Civil Engineering, v. 48, no. 4, p. 47-51.

Meetings

The TENTH RAPID EXCAVATION AND TUNNELING CONFERENCE, **June 16-20, 1991,** Seattle, Washington. For additional information contact the Meetings Department, SME, P.O. Box 625002, Littleton, CO 80162, or call (303) 973-9550, FAX (303) 979-3461.

LAKE BONNEVILLE FIELD TRIP: Stratigraphy, sedimentation, fossils, soils, and tephra near Delta, Utah, **October 11-13, 1991.** Contact Richard Van Horn, U.S. Geological Survey, Box 25046, MS 966, Denver, Colorado 80225.

The 1992 SME ANNUAL MEETING AND EXHIBIT, **February 24-27, 1992,** Phoenix, Arizona. Contact Meetings Department, SME, P.O. Box 625002, Littleton, CO 80162, (303) 973-9550, FAX (303) 9979-3461.

CALL FOR PAPERS: The 1992 Utah Geological Association field trip and guidebook will focus on "Engineering and Environmental geology of southwestern Utah." One-page abstracts are due by June 1, 1991 for all aspects of the subject: geologic hazards (earthquakes, landslides, flooding, problem soils, etc.), surface and subsurface hydrology, water supply, facility siting, dams, mine reclamation, waste disposal, and slope stability. Papers covering southeast Nevada or northwest Arizona are also encouraged. Contact Kimm M. Harty, Utah Geological and Mineral Survey, 606 Black Hawk Way, Salt Lake City, Utah 84108, (801) 581-6831 or Fax (801) 581-4450.

Dixie Geological Association Formed in St. George

Geologists from across southern Utah met at Dixie College on January 30, 1991 to establish the Dixie Geological Association. More than 40 people, including spouses, showed up for a buffet supper and organizational meeting in the college's cafeteria. Participants came from mining companies, consulting firms, colleges, and the ranks of the retired.

Spense Reber, retired geologist from Chevron Corp., and Kelly Bringhurst, geology instructor at Dixie College, were chosen co-chairs of the group. Meetings will be held on an irregular basis with guest speakers. The DGA is planning a series of geologic field trips through the region with the first planned for the spring. Locations of the trips are still to be decided.

State Geologist Dr. M. Lee Allison was the featured speaker at the meeting, giving an update on current oil and gas activity in Utah with an emphasis on the Precambrian source rock play.

For additional information on the association and its activities contact Kelly Bringhurst at Dixie College: Science Building, 225 South 800 East, St. George, Utah, 84770, (801) 673-4811.

Staff Changes

UGMS Economic/Mapping Sections hired *Deborah Jordan* as the new secretary. Deborah has a B.A. in Journalism from the University of Texas at Arlington, and most recently served as an administrative assistant for a manufacturing firm in Cincinnati. The staff is delighted to have Ms. Jordan aboard!

Daniel Kelly has accepted the position of UGMS Budget and Accounting Officer. Dan has a B.S. in accounting and 7-plus years experience in a variety of accounting positions across the country. Sharpen the pencils and shine the 10-key!

Suzanne Hecker, geologist with the Applied Section, has accepted a position with the U.S. Geological Survey. She has been cataloging the Quaternary tectonics of Utah (see her article in this issue) and will have a map available in late 1991. Now she gets to trench the San Andreas fault. Best of luck!

The following information has been released from confidential status by the U.S. Bureau of Land Management and is now available to the general public from the UGMS archives: all geologic and geophysical data and maps for the area are encompassed by U-7959, a former Federal coal lease, with these drill holes —

T. 22 S., R. 7 E., Sec. 4, Federal #3
T. 22 S., R. 7 E., Sec. 7, 8-E
T. 22 S., R. 7 E., Sec. 8, 10-E
T. 22 S., R. 7 E., Sec. 17, Federal #6
T. 22 S., R. 7 E., Sec. 18, Federal #1, 2A, 3A, 5A, 6A
For information, contact UGMS Library.

Teacher's Corner

by Sandra N. Eldredge

Great Salt Lake Trivia

1. WHAT IS THE AVERAGE SALT CONTENT OF THE GREAT SALT LAKE (GSL)?
2. WHAT IS THE AVERAGE DEPTH OF THE LAKE?
3. HOW MANY SALT OPERATIONS HAVE THERE BEEN ON THE LAKE?
4. WHICH OPERATION MARKETED ITS SALT FOR MAKING CHEESE AND WHERE WAS IT LOCATED?
5. HOW MANY TONS OF SALT ARE CONTAINED IN THE GSL? HOW MANY TONS OF SALT ARE PRODUCED A YEAR?
6. WHAT RESOURCES ARE CURRENTLY EXTRACTED FROM THE GSL?
7. WHAT ARE THE LOWEST AND THE HIGHEST RECORDED LEVELS OF THE GSL?
8. HOW MANY ISLANDS ARE IN THE GSL? NAME THEM.
9. WHAT ARE THE WHITE BEACHES MADE OF?

Classroom activity:

Compare the salt content of the Great Salt Lake and the Pacific Ocean. Visually illustrate with two graduated cylinders: one with 25% salt for the GSL, and the other showing 3% salt for the ocean.

Announcements:

Contact the Utah Museum of Natural History for schedule of teacher inservice classes (581-6927).

Publications:

Contact UGMS for a selected UGMS list of publications for teachers (free).

Two recent UGMS publications you may be interested in are:

A Salt Lake Valley field trip guide for educators teaching 8th grade earth science, Bemis, G., 1990, 46 p., Open-File Report 200 ($3.75). A basic guide to various geologic features includes five stops (for school buses) each in three areas of the valley. Matches specific state core curriculum standards and objectives, contains labeled diagrams and photos, and worksheets.

The Great Salt Lake Information Sheet, UGMS, 1990, Public Information Series #8 (free). One page lists facts about the Great Salt Lake and includes an illustration of the lake.

Answers:

1. The average salt content is 25%, with a range of 9% to 28%. In comparison, the ocean contains about 3% salt.
2. Average depth is 13 feet when the lake level is at 4200 feet. The maximum depth range is 25 feet to 45 feet.
3. Over 20 salt operations. First operations began in the 1860s encouraged by a market in Montana needing salt for silver production.
4. Quaker Crystal Salt Company produced salt from Spring Bay (northern arm of GSL) between 1939 and 1965. Salt was extracted both from the lake and from three warm springs on shore which began to flow after an earthquake. The salt from the warm springs was apparently suitable for cheese making.
5. Over 4.5 billion tons of salt are contained in the GSL. Sometimes a million tons of salt per year are produced from the lake.
6. Sodium chloride (table salt), sodium sulfate (salt cake), potassium sulfate (sulfate of potash), magnesium chloride brine and solid, magnesium metal, chlorine gas, brine shrimp and eggs. In the past, attempts were made to propagate oysters, fish, and eels at mouths of streams.
7. Lowest recorded level is 4191.30 feet (1963). Highest recorded level is 4211.85 feet (1987).
8. Ten islands at lowest water level: Antelope, Badger, Carrington, Cub, Dolphin, Egg, Fremont, Gunnison, Hat (Bird), Stansbury. Cub and Egg disappear at high water level.
9. Oolites. Oolitic sand begins with a small nucleus around which calcium carbonate grows outward and forms round grains. Each grain is of very round shape, called an oolite due to its resemblance to a fish egg. Usually the nucleus is a pellet from the brine shrimp digestive system.

Quaternary Tectonics of Utah

by Suzanne Hecker

INTRODUCTION

Tectonics pertains to the evolving configuration of the outer part of the earth; it involves magmatic activity and deformation on faults, folds, and other structural features in the crust. This article highlights important aspects of tectonics in Utah during the last 1½ million years, especially as they relate to future earthquakes.

Stresses within the earth build up until they exceed the strength of a body of rock, resulting in sudden, earthquake-generating fault movements or, under certain circumstances, more gradual, relatively aseismic deformation. Earthquakes which are large enough to cause fault rupture at the earth's surface leave an imprint on the landscape. This geomorphic evidence can be used to reconstruct the history of large prehistoric earthquakes. Deciphering the geologic record and reconstructing the recent history of tectonic activity are important for evaluating the occurrence of future large earthquakes and ground-deforming events.

PHYSIOGRAPHY AND TECTONIC SETTING

The physiography (landform patterns) of Utah in part reflects the cumulative effect of many faulting and other crust-deforming events occurring over millions of years. In particular, the deformation responsible for large-scale landforms in western Utah, Nevada, and portions of several other western states is mainly due to east-west extension which is slowly pulling the earth's crust apart. In this region, known as the Basin and Range physiographic province, a characteristic pattern of narrow, north-south-trending mountain ranges separated by basin valleys (figure 1) has developed over the last 10 to 15 million years from repeated normal-slip events on high-angle, range-bounding faults (figure 2).

Although the north-south-trending boundary of the Basin and Range province in Utah (figure 1) generally marks the eastern extent of classic basin-and-range physiography, it does not coincide with the eastern limit of basin-and-range faulting. There is, in fact, geomorphic and stratigraphic evidence for this type of extensional faulting in a 100-km-wide (60 mi) zone east of the Basin and Range province, within the western margin of the Middle Rocky Mountains and Colorado Plateau physiographic provinces (figure 1).

Normal faulting in the Middle Rocky Mountains Province has formed small intermountain basins, such as Ogden and Morgan Valleys. Cache and Bear Lake Valleys are larger structural valleys that extend into Idaho, and are somewhat similar to valleys further west in the Basin and Range province. A major relict of pre-basin-and-range tectonics is the Uinta Mountains, the only east-west-trending range in Utah and a principal feature of the Middle Rocky Mountains Province.

Normal faulting has also encroached upon and fragmented the western margin of the Colorado Plateau, creating tablelands (such as the Gunnison, Sevier, and Markagunt Plateaus) separated by relatively narrow, north-south-trending valleys (such as Sanpete and Sevier Valleys). Known along much of its length as the High Plateaus (figure 1), this physiographic transition zone has an especially complex tectonic history, which includes multiple generations and types of crustal deformation. Besides faulting, the most recent phase of tectonic activity in the region has involved volcanism and salt tectonics (formation of structures due to the upwelling of low-density, salt-rich rocks and near-surface dissolution of salt). Young volcanic activity has been widespread in southwestern Utah (figure 3) and has involved eruptions of basalt flows, cinder, and ash. Salt tectonics has affected the northern High Plateaus at least locally, although the regional extent and long-term significance of the phenomenon is open to different interpretations (for example, Standlee, 1982; Witkind, 1982).

Salt tectonics has played a primary role in the geologic evolution of a subregion of the Colorado Plateau known as the Paradox Basin (figure 1). Here, recurrent episodes of upwelling and dissolutional collapse have left a record of disrupted sedimentation patterns and locally intense deformation (see Doelling and others, 1988). The modern landscape includes a series of collapse valleys, notably Spanish, Salt, Fisher, and Castle Valleys, formed along the crests of long, northwest-trending salt-cored folds.

Notwithstanding the salt-related deformation of the Paradox Basin, the interior of the Colorado Plateau province is underlain by relatively stable, coherent crust and is essentially unaffected by basin-and-range faulting. However, the plateau has experienced significant uplift during the period of time that the terrain to the west has been faulted (Morgan and Swanberg, 1985).

THE WASATCH AND HANSEL VALLEY FAULTS: EXAMPLES OF EARTHQUAKE SOURCES

The tectonic processes which, over millions of years, have shaped Utah's landscape continue to be active, presenting a hazard to society. Perhaps a dozen or more earthquakes large enough to cause fault rupture at the earth's surface have occurred on several faults in Utah in the past two to three thousand years (see compilation by Hecker, in preparation). Most of these large earthquake events occurred on the Wasatch fault and one, on the Hansel Valley fault (figure 1), occurred slightly more than 50 years ago.

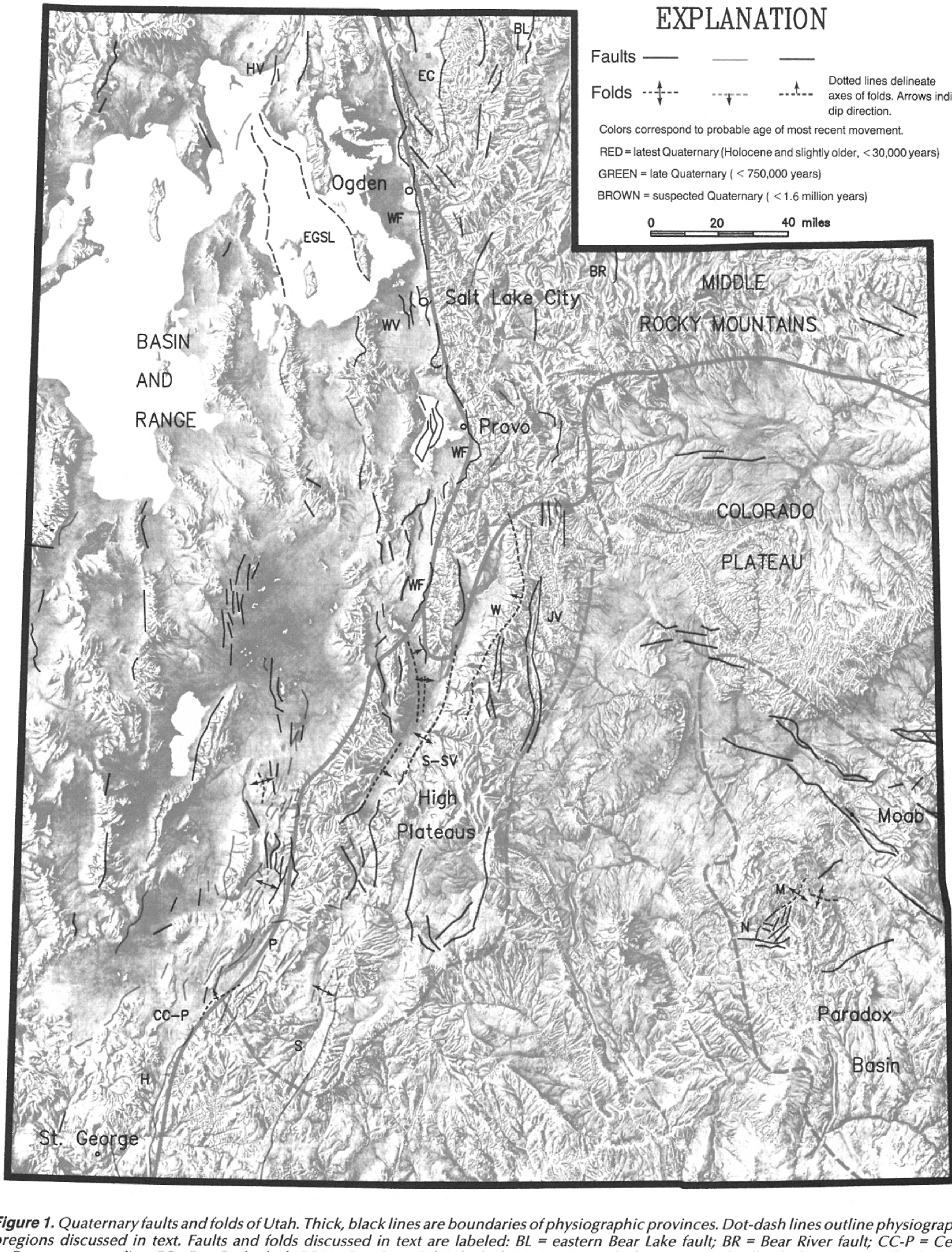


Figure 1. *Quaternary faults and folds of Utah. Thick, black lines are boundaries of physiographic provinces. Dot-dash lines outline physiographic subregions discussed in text. Faults and folds discussed in text are labeled: BL = eastern Bear Lake fault; BR = Bear River fault; CC-P = Cedar City-Parowan monocline; EC = East Cache fault; EGSL = East Great Salt Lake fault; H = Hurricane fault; HV = Hansel Valley fault; JV = Joes Valley fault; N = Needles fault zone; M = Meander anticline; P = Paragonah fault; S = Sevier fault; S-SV = Sanpete-Sevier Valley anticline; W = Wasatch monocline; WF = Wasatch fault; WV = West Valley fault zone.*

The 1934 Hansel Valley earthquake had a magnitude (M_L) of about 6.6, which is thought to be slightly above the threshold for surface-fault rupture. During the earthquake, the ground surface was displaced as much as 0.5 m (1.6 ft), creating small fault scarps along a 6 km (3.7 mi) trace of the fault (see photo on cover). A study of prehistoric fault scarps and the faulted sediments beneath them shows that this historic earthquake was not unprecedented: one or two earthquakes accompanied by a meter or more of displacement had occurred along this same fault about 13,000 to 15,000 years ago, and other events had occurred even earlier (McCalpin and others, 1987). This type of information on the displacement histories of faults is essential for estimating the likelihood of future large earthquakes and for evaluating all earthquake hazards.

The best-studied, and the most active, tectonic feature in Utah is the Wasatch fault. The Wasatch, like many faults, is comprised of discrete, independent segments, each of which is capable of generating a large-magnitude earthquake. Geologists began examining evidence for past earthquakes on the Wasatch fault in the mid-1970s, although a hundred years earlier a perceptive geologist named G.K. Gilbert recognized the significance of scarps he saw along the base of the Wasatch Range (see Lund, 1988, for a review of Gilbert's work). Gilbert was especially impressed with conspicuous scarps which cross glacial moraines and stream alluvium at the mouths of Bells and Little Cottonwood Canyons, south of Salt Lake City (figure 4). The main scarp in this area reaches a height of 45 meters (150 ft) and is undoubtedly the result of multiple surface-faulting events. Recent detailed work (also summarized in Lund, 1988) indicates that this portion of the fault zone, which lies at the south end of the Salt Lake City segment, has had at least three large earthquakes in the past 8000 to 9000 years, with up to 5.0 m (16 ft) of net surface displacement per event. Surface ruptures produced during earthquakes on the 46-km-long (28.5 mi) Salt Lake City segment, or on the other central segments of the Wasatch fault, were many times larger than the rupture produced during the 1934 Hansel Valley earthquake. Comparisons of rupture dimensions measured from the geologic record of the Wasatch fault with the rupture dimensions for large historic earthquakes in the region (such as the magnitude 7.3, 1983 Borah Peak earthquake in Idaho) indicate that the Wasatch fault has produced earthquakes with magnitudes (M_S) of 7.5 to 7.7 (Arabasz and others, 1987; Youngs and others, 1987; Machette and others, in press).

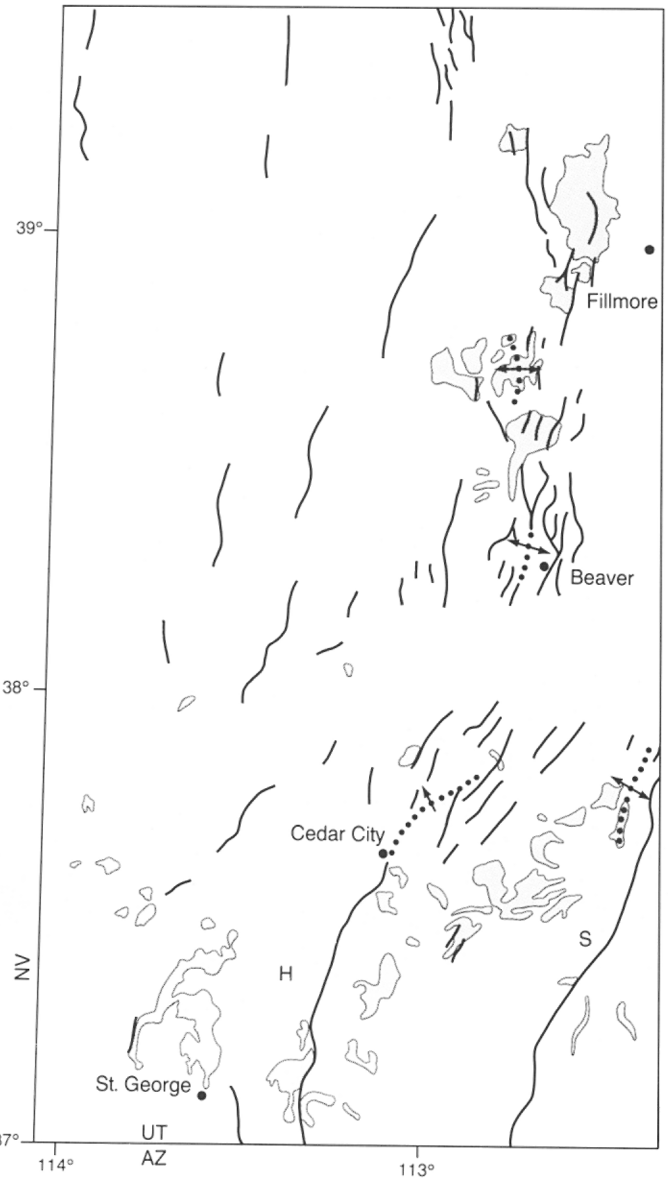


Figure 3. *Young volcanic rocks (shaded) of southwestern Utah in relation to Quaternary faults and folds (from figure 1). "H" and "S" refer to the Hurricane and Sevier faults, respectively. Areas of volcanic rocks are modified from Luedke and Smith (1978).*

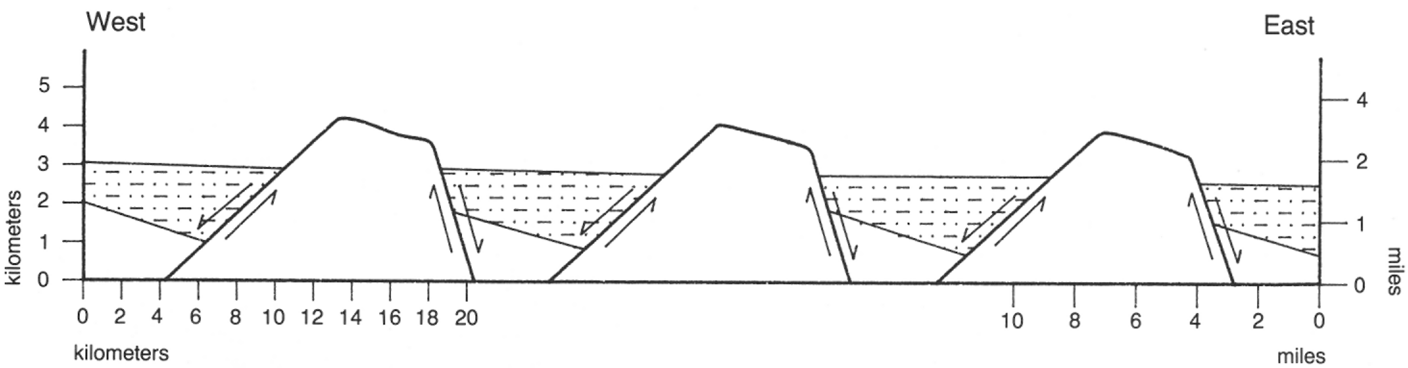


Figure 2. *Schematic cross section across a portion of the Basin and Range province with general relation of fault blocks and physiography. Stippled areas are basin-fill deposits; unpatterned areas are bedrock. Arrows indicate relative direction of movement (valley-block down; mountain-block up) on range-bounding normal faults. Vertical scale is two times the horizontal scale.*

Figure 4. *Wasatch fault where it crosses the mouths of Little Cottonwood Canyon (left side of picture) and Bells Canyon (center) in southern Salt Lake County. Bells Canyon Reservoir lies within the fault zone at the terminus of the Bells Canyon glacial moraines. Fault scarps lie in shadow; view is to the east.*

DATABASE OF QUATERNARY TECTONIC FEATURES: EVALUATING EARTHQUAKE POTENTIAL

The Hansel Valley and Wasatch faults are only two examples of many active faults which have been identified in Utah. Although the earthquake histories of the vast majority of faults have not been studied in detail, an abundance of useful information on the approximate ages and physical characteristics of faults is available from geologic mapping, preliminary paleoseismic studies, and other types of geologic studies.

To make this information readily available in a convenient format, the Utah Geological and Mineral Survey has compiled a statewide map (simplified in figure 1) and computerized database of information on tectonic features known or suspected of being active during the Quaternary Period (the past 1.6 million years) (Hecker, in preparation). The compilation updates the "Quaternary fault map of Utah" by Anderson and Miller (1979) and incorporates regional and site-specific studies by geologists from the Utah Geological and Mineral Survey, the U.S. Geological Survey, the U.S. Bureau of Reclamation, other government agencies, universities, and private consulting firms.

The database contains the following types of geologic information used to characterize the earthquake potential and general activity of faults: 1) age of most recent surface-faulting event; 2) cumulative displacement averaged over time (slip rate); 3) time period between successive surface-faulting events (recurrence interval); 4) amount of surface-faulting displacement during individual events; and 5) length of surface fault rupture (table 1). The compilation also includes folds and volcanic rocks, mainly targeting available age information. These features are included because they are spatially associated with faults in some areas of the state (figures 1 and 3), and they provide insight into local mechanisms of deformation occurring within regimes of basin-and-range faulting. Some of these local mechanisms may produce surface ruptures without generating large earthquakes.

Large, plateau- and range-front folds (such as the Wasatch and Cedar City-Parowan monoclines, figure 1) may lie above major hidden faults capable of producing large earthquakes. Other, smaller folds lie adjacent to major block-bounding faults (such as the fold along the north end of the Sevier fault, figure 1) and may be the result of shallow, secondary deformation caused by movement on the primary faults. Faults which cut the crests and limbs of folds (such as small faults on the fold near the Sevier fault, and possibly the Joes Valley graben and other graben structures above the Wasatch monocline, figure 1) may also be relatively shallow structures related to fold growth, and they may not be capable of generating large earthquakes.

Upwelling of salt-rich rocks has apparently created some fold and dome structures, such as the Sanpete-Sevier Valley anticline in central Utah and the Meander anticline in the Paradox Basin (figure 1). Surface faulting within areas of salt tectonics may be partly related to dissolution and collapse of salt structures and may not be accompanied by significant earthquakes. Holocene faulting and folding in the southern portion of the Paradox Basin are probably due to a combination of salt and gravity tectonics. Downcutting by the Colorado River has evidently reduced the rock load on salt-rich deposits, causing the salt to flow or be compressed as extension or gravity sliding occurred in overlying rocks, thus forming the Meander anticline and the Needles fault zone (figure 1) (for example, see McGill and Stromquist, 1974; Huntoon, 1982).

In areas of young volcanic rocks in southwestern Utah (figure 3), some faults may be related to volcanic processes, such as subsidence above magma chambers, and may have formed without generating large earthquakes. Vents and cones within a north-south-trending group of volcanic rocks north of 38° north latitude (figure 3) generally lie along short intrabasin faults, which have controlled the surface expression of volcanism (Nash, 1986), and which may have served as conduits for the magma (Hoover, 1974). In contrast, volcanic vents to the south do not generally occur along mapped faults. Some flows do cross major faults (such as the Sevier and Hurricane faults, figure 3), although the vents can be seen to be localized on the up-thrown side of the faults (Anderson and Christenson, 1989).

SPACE-TIME PATTERNS OF QUATERNARY TECTONISM

Quaternary tectonism, principally normal faulting, is concentrated within a broad north-south-trending zone along the transitional eastern boundary of the Basin and Range province (figure 1). This zone of young crustal deformation is also aligned with a zone of historical seismicity known as the Intermountain seismic belt (see Christenson, this issue, for discussion). Quaternary tectonic features are sparse in portions of the Basin and Range province in Utah (specifically, in the northwest corner of the state and near the southwest border with Nevada) and throughout the interior of the Middle Rocky Mountains and Colorado Plateau, with the notable exception of the Paradox Basin (figure 1).

During the late Quaternary (the past several hundred thousand years), tectonic activity has been distributed along much of the eastern boundary region of the Basin and Range province. However, during the Holocene Epoch (the past 10,000 years), tectonic activity has been largely absent from southern Utah, while rates of activity have increased on the central segments of the Wasatch fault. In addition, other faults in the Wasatch Front region have experienced Holocene or slightly older surface-faulting events, and many faults in west-central Utah have evidence for a single surface-faulting event during the Holocene.

Two subparallel structures which bound highlands on the transitional western margin of the Colorado Plateau in southwestern Utah may have among the highest late-Quaternary slip rates in Utah. The Hurricane fault, along with its northward continuation as the Cedar City-Parowan monocline and Paragonah fault (figure 1), has an average late-Quaternary slip rate of 0.3 to 0.5 mm/yr (0.01-0.02 in/yr) (Anderson and Christenson, 1989). The Sevier fault (figure 1) has a late-Quaternary slip rate of about 0.4 mm/yr (0.02 in/yr) (Anderson and Christenson, 1989). These values are somewhat greater than slip rates of 0.1 to 0.2 mm/yr (0.004-0.008 in/yr) estimated for the Wasatch fault for the late Quaternary (Machette and others, 1986) but are comparable to, or less than, rates of 0.4 to 0.7 mm/yr (0.015-0.03 in/yr) estimated for the East Great Salt Lake fault (figure 1) for the entire Quaternary (Pechmann and others, 1987).

Table 1.

Two sample entries from the database of Quaternary tectonic features (modified from Hecker, in preparation). Ages are expressed in ka (thousands of years).

NAME OR LOCATION OF STRUCTURE	AGE OF MOST RECENT MOVEMENT ka	SLIP RATE mm/yr (Time Period, ka)	RECURRENCE INTERVAL X1000 yr (Time Period, ka)	DISPLACEMENT PER EVENT m	RUPTURE LENGTH km
Sevier fault					
Parameter values:	late Quaternary	0.36 (<560)			

Age Criteria : Amount of displacement in mid-Pleistocene deposits; basin closure; range-front morphology; alluvial-fan characteristics; K-Ar
Reference : Anderson and Christenson, 1989
Comments : Striations with a southerly component of rake indicate that the Sevier fault has sinistral-normal slip. A small closed basin adjacent to a left step in the south end of the fault is consistent with dilation due to sinistral slip and indicates that subsidence and fault activity (due either to surface-faulting earthquakes or low-level seismicity/aseismic creep) are likely late Pleistocene in age. Further north on the fault....

NAME OR LOCATION OF STRUCTURE	AGE OF MOST RECENT MOVEMENT ka	SLIP RATE mm/yr (Time Period, ka)	RECURRENCE INTERVAL X1000 yr (Time Period, ka)	DISPLACEMENT PER EVENT m	RUPTURE LENGTH km
Bear River fault					
Parameter values:	3.0	0.9 - 2.63 (< 4.3)	1.3 - 3 + (< 4.3)	1.3 - 5.1	37 +

Age Criteria : ^{14}C
Reference : West, 1986, 1987, 1988
Comments : The Bear River fault zone extends from southeast of Evanston, Wyoming to the Uinta Mountains in Utah, where it ends at a complex juncture with the North Flank fault. Scarps at the south end of the zone are sharply discordant with the main, northerly trend of faulting. The fault zone lies between the leading edges of the Absaroka and Darby thrust faults and appears to be a new (Holocene) feature superimposed on older thrustbelt structure....

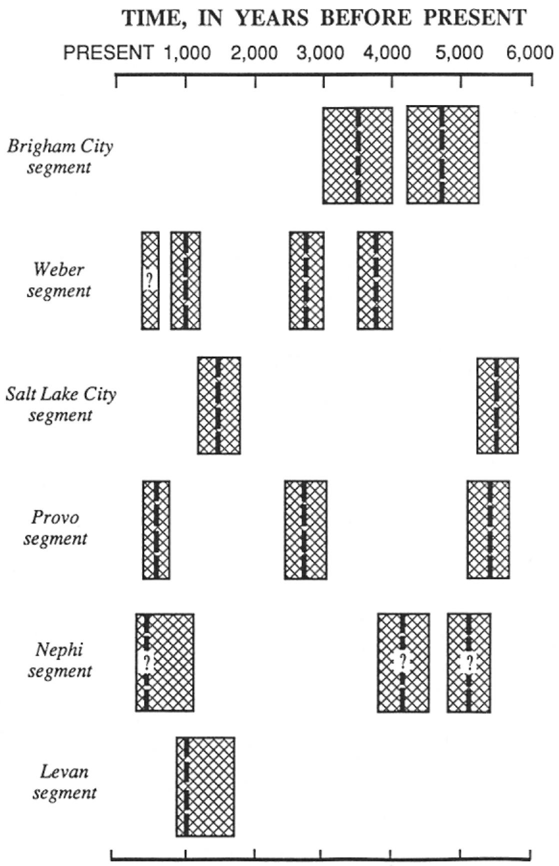


Figure 5. *Timing of earthquakes on segments of the Wasatch fault during the middle to late Holocene. Heavy dashed lines indicate best estimates for times of faulting; cross-hatchured areas indicate likely time limits based on available age estimates (Machette and others, in press).*

This long-term (late Quaternary) distribution of tectonic activity contrasts with patterns of recent, short-term activity. Little or no deformation has occurred during the Holocene along the Hurricane or Sevier faults, or on most other tectonic features near the southern border of the state (figure 1). On the other hand, Holocene activity on the central Wasatch fault (1-2 mm/yr; 0.04-0.08 in/yr; Machette and others, in press) has been much higher than over the long term, with a ten-fold increase in the rate of slip.

Recurrence intervals for surface-faulting earthquakes on individual segments of the central Wasatch fault have varied from about 500 years to 4000 years during the middle to late Holocene (the past 6000 years) (figure 5). The "composite recurrence interval" (average time between two events anywhere along the central part of the fault) for this time period is about 400 years (Machette and others, in press). However, there was a pulse of earthquake activity between about 400 and 1500 years ago, when almost the entire central portion of the fault ruptured (figure 5). The average composite recurrence interval for this time period is about 220 years, about half the longer term Holocene value (Machette and others, in press).

At least a dozen other faults within the Intermountain seismic belt east and west of the Wasatch fault have had one or more Holocene (or slightly older) surface-faulting event(s) (figure 1). This group of faults includes: 1) the Hansel Valley fault, where surface-faulting earthquakes occurred in 1934 and 13,000 to 15,000 years ago (McCalpin and others, 1987); 2) the central segment of the East Cache fault, where events occurred about 6000 to 9000 and 13,500 to 15,000 years ago (McCalpin, 1989); 3) the southern segment of the eastern Bear Lake fault, where the latest of two(?) Holocene events occurred about 2000 years ago (McCalpin, 1990); 4) the Bear River fault, where faulting occurred 3000 and 4300 years ago (West, 1987); and 5) the West Valley fault zone, where multiple events have occurred during the Holocene (Keaton and others, 1987; Keaton and Currey, 1989) (figure 1). Based on current information, a preferred estimate of 90 surface-faulting events have occurred in the past 15,000 years in this region of north-central Utah. This translates into an average regional recurrence interval for this time period of 170 years (Hecker, in preparation). Proposed segment (rupture) lengths for Quaternary faults other than the central Wasatch fault are typically between 10 and 30 km (about 5 and 20 mi), considerably shorter than lengths of the most active segments of the Wasatch fault, which average about 50 km (30 mi).

The Basin and Range province of west-central Utah, between about 38.5° and 40° north latitude, has a unique pattern of single-event Holocene (and slightly older) displacements distributed across a series of widely spaced faults (figure 1). Further east, within the Basin and Range-Colorado Plateau transition zone (the High Plateaus, figure 1), faults are also characterized by a single, or in some cases multiple, Holocene surface-faulting event(s). The broad similarity in ages of surface faulting within this latitude belt may be related to widespread movement on a system of extensive low-angle faults that apparently underlie the region and have been identified on seismic profiles (Standlee, 1982; Allmendinger and others, 1983; Smith and Bruhn, 1984; Arabasz and Julander, 1986). The mechanics of movement on these low-angle faults are poorly understood and, consequently, the earthquake potential of faults in this region is somewhat less certain than on faults that dip more steeply. In addition, faults within the eastern portion of this Holocene fault belt are in a region of possible salt tectonics and, consequently, may experience movement related to collapse of rock above areas of salt dissolution rather than to association with large earthquakes.

REFERENCES

Allmendinger, R.W., Sharp, J.W., Von Tish, D., Serpa, L., Brown, L., Kaufman, S., and Oliver, J., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range province, Utah, from COCORP seismic-reflection data: Geology, v. 11, p. 532-536.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Fugro Incorporated, Long Beach, California, 35 p., scale 1:500,000.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p.

Arabasz, W.J., and Julander, D.R., 1986, Geometry of seismically active faults and crustal deformation within the Basin and Range-Colorado Plateau transition in Utah, *in* Mayer, Larry, editor, Extensional Tectonics of the Southwestern United States—A Perspective on Processes and Kinematics: Geological Society of America Special Paper 208, p. 43-74.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1987, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume I: U.S. Geological Survey Open-File Report 87-585, p. D-1-58.

State of Utah
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

Norman H. Bangerter, Goveror
Dee C. Hansen, Executiver Director
M. Lee Allison, State Geologist

606 Black Hawk Way • Salt Lake City, UT 84108-1280 • 801-581-6831

Dear Fellow Geoscientists:

The Utah Geological and Mineral Survey receives numerous inquiries for geologic information on areas of Utah where published material is lacking or inadequate. Frequently, inquiries pertain to areas where research is planned, currently underway, or completed but unpublished. If you and/or co-workers are conducting research in Utah during 1991-92, would you let us know by filling out and returning the insert. We use this information to improve our knowledge of pertinent Utah research projects and to direct other scientists to critical geologic information.

Please circulate this form among your colleagues and/or staff and return as soon as possible. Photocopies are acceptable. More forms are available upon request at no charge.

Responses to this survey will be entered into the UGMS "Geologic Projects in Utah" database, and published each spring in *Survey Notes.* Database searches made by investigator, county, type of study, and scale of mapping are available at no charge. Please write for more information, attention Michael Ross.

Many thanks for your cooperation.

M. Lee Allison
Utah Geological and Mineral Survey

(Please pull out insert, fill in information and return to UGMS)

Investigator(s): ______________________________

Organization/School: ______________________________

Address: ______________________________

Utah County(ies): ____________ (refer to Utah County codes on map on reverse side)

Location: ______________________________

____

Type of Study: ____________ (refer to type of study codes on reverse side)

Title/Subject: ______________________________

____

Scale of Geologic Mapping: ____________ (if applicable)

Economic Geology Commodities: ____________ (if applicable)

Date of Inception: ____________ Date of Completion: ____________

Location of Information (i.e., University thesis; government or technical agency open-file report; other publication; company confidential — where, release date, and provisions): ______________________________

____

____

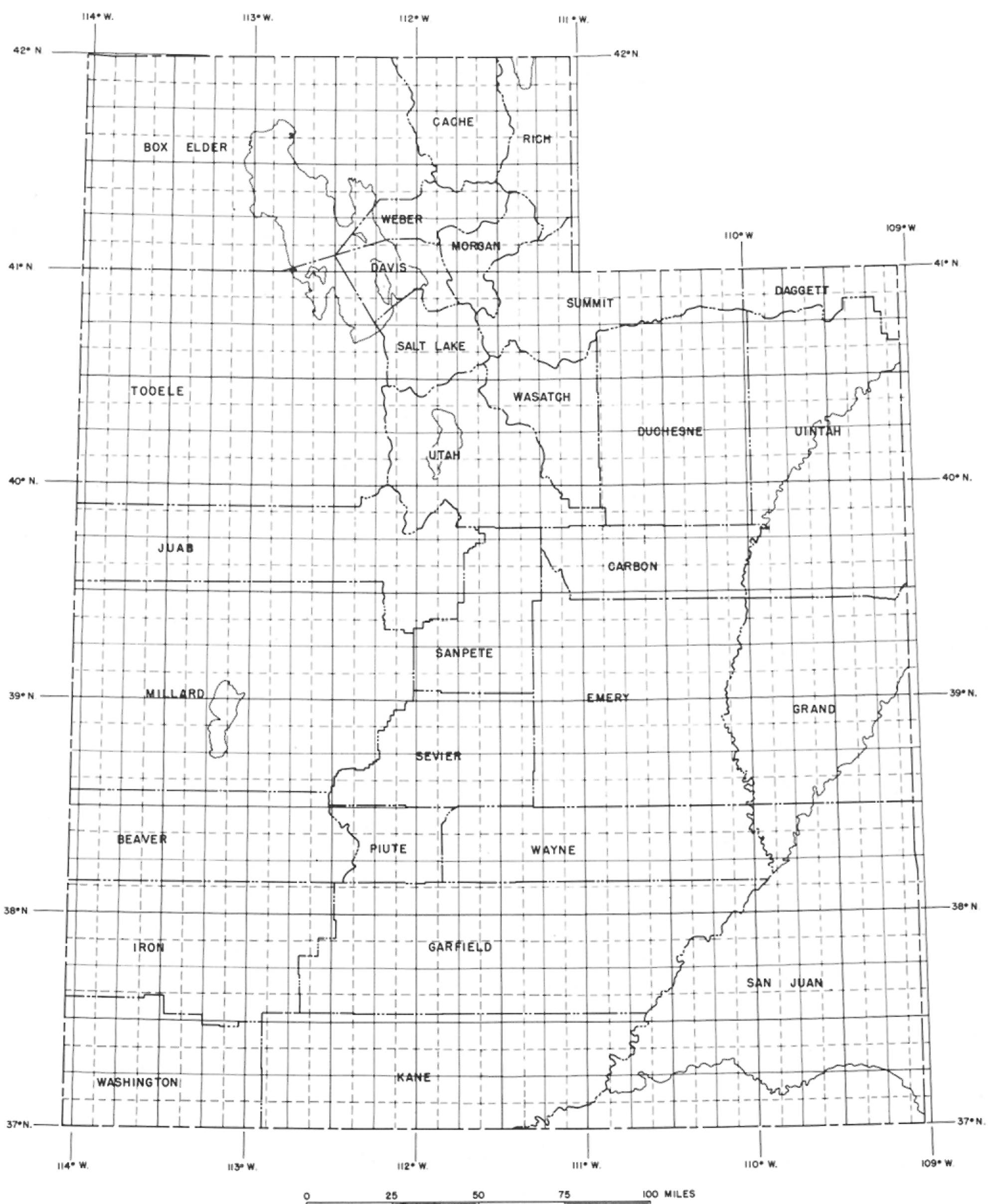
May the UGMS have a copy of the completed report and/or map for our library? ☐ yes ☐ no

(Seal or Staple Here)

PLACE STAMP HERE

Utah Geological and Mineral Survey
606 Black Hawk Way
Salt Lake City, Utah 84108-1280

Attn. Michael Ross



IF POSSIBLE, PLEASE FILL IN LOCATION OF STUDY AREA ON THIS MAP OF UTAH.
EACH SMALL SQUARE EQUALS ONE 7-1/2 MINUTE QUAD.

Explanation for **Type of Study** codes

Economic Geology:	
a. General	EC
b. Coal	CG
c. Geothermal	GG
d. Minerals	MG
e. Petroleum	PG
f. Salines	SG
Engineering Geology	EG
Environmental Geology	EV
Geochemistry	GC
Geochronology	GR
Geologic Hazards	GH
Geologic Mapping	GM
Geophysics	GP
Hydrogeology	HG
Mineralogy	MN
Paleomagnetism	PM
Paleontology:	
a. Undifferentiated	PU
b. Invertebrate	PI
c. Vertebrate	PV
Palynology/Paleobotany	PY
Petrology	PT
Quaternary Geology	QG
Sedimentology	SD
Stratigraphy	SR
Structural Geology/Tectonics	ST
Volcanology	VO

Explanation for **County** codes

Beaver	BE
Box Elder	BX
Cache	CA
Carbon	CR
Daggett	DG
Davis	DA
Duchesne	DU
Emery	EM
Garfield	GA
Grand	GR
Iron	IR
Juab	JU
Kane	KA
Millard	MI
Morgan	MO
Piute	PI
Rich	RI
Salt Lake	SL
San Juan	SJ
Sanpete	SA
Sevier	SE
Summit	SU
Tooele	TO
Uintah	UI
Utah	UT
Wasatch	WS
Washington	WA
Wayne	WN
Weber	WE
Statewide	SW

Doelling, H.H., Oviatt, C.G., and Huntoon, P.W., 1988, Salt deformation in the Paradox region: Utah Geological and Mineral Survey Bulletin 122, 93 p.

Hecker, Suzanne, in preparation, Quaternary tectonics of Utah—with emphasis on seismic source characterization: Utah Geological and Mineral Survey Special Studies.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Huntoon, P.W., 1982, The Meander anticline, Canyonlands, Utah, an unloading structure resulting from horizontal gliding on salt: Geological Society of America Bulletin, v. 93, p. 941-650.

Keaton, J.R., and Currey, D.R., 1989, Earthquake hazard evaluation of the West Valley fault zone in the Salt Lake City urban area, Utah: Unpublished Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-G1397, 69 p.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Unpublished Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.

Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of Late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigation Series Map I-1091-B, scale 1: 1,000,000.

Lund, W.R., 1988, The Wasatch fault zone, earthquakes and Salt Lake City: G.K. Gilbert to the present: Utah Geological and Mineral Survey, Survey Notes, v. 22, no. 3, p. 3-10.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1986, Late Quaternary segmentation and slip-rate history of the Wasatch fault zone, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 67, no. 44, p. 1107.

Machette, M.N., Personious, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., in press, The Wasatch fault zone, Utah — Segmentation and history of Holocene earthquakes: Journal of Structural Geology.

McCalpin, James, 1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

McCalpin, James, 1990, Latest Quaternary faulting in the northern Wasatch to Teton Corridor (NWTC): Unpublished Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1396, 42 p.

McCalpin, James, Robison, R.M., and Garr, J.D., 1987, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume I: U.S. Geological Survey Open-File Report 87-585, p. G-1-44.

McGill, G.E., and Stromquist, A.W., 1974, A model for graben formation by subsurface flow; Canyonlands National Park, Utah: Department of Geology and Geography Contribution No. 15, University of Massachusetts, Amherst, 79 p.

Morgan, P., and Swanberg, C.A., 1985, On the Cenozoic uplift and tectonic stability of the Colorado Plateau: Journal of Geodynamics, v. 3, p. 39-63.

Nash, W.P., 1986, Distribution, lithology and ages of late Cenozoic volcanism on the eastern margin of the Great Basin, west-central Utah: University of Utah Research Institute Earth Science Laboratory unpublished Final Report for U.S. Department of Energy under contract DEAC0780 ID 12079, DOE/ID/12079-131, 82 p.

Pechmann, J.C., Nash, W.P., Viveiros, J.J., and Smith, R.B., 1987, Slip rate and earthquake potential of the East Great Salt Lake fault, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 68, no. 44, p. 1369.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the western U.S. Cordillera—inferences on structural style from seismic reflection data, regional tectonics and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, p. 5733-5762.

Standlee, L.A., 1982, Structure and stratigraphy of Jurassic rocks in central Utah—their influence on tectonic development of the Cordilleran foreland thrust belt, *in* Powers, R.B., editor, Geologic Studies of the Cordilleran Thrust Belt, Volume I: Rocky Mountain Association of Geologists, Denver, Colorado, p. 357-382.

West, M.W., 1987, Surface rupture characteristics, recurrence intervals and slip rates determined by trenching, Bear River fault zone, Wyoming and Utah [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 341.

Witkind, I.J., 1982, Salt diapirism in central Utah, *in* Nielson, D.L., editor, Overthrust Belt of Utah: Utah Geological Association Publication no. 10, p. 13-30.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P, and Green, R.K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585, p. M-1-110.

National Review Panel Gives High Ratings to Utah's Seismograph Stations

Utah's was one of 27 regional seismic networks studied by a seven-member national panel of top scientists headed by John R. Filson of the USGS. The USGS convened the panel of experts to review the status of, and funding options for, regional earthquake-recording networks in the United States. The panel was directed to make recommendations to the USGS on future policy toward regional networks.

The review panel notes the Utah Seismograph Stations, headquartered in the Department of Geology and Geophysics, "serve as principal source of information on earthquakes and earthquake hazards throughout the State." The network is a key part of the seismology program at the U. of U. and is the only facility of its kind in the Intermountain area. Dr. Walter J. Arabasz, research professor of geology and geophysics, directs the regional network, which detects and analyzes about 2,900 seismic events annually.

The federal panel says the seismograph operation "has become more aggressive in the past few years in bringing the earthquake safety message to the public."

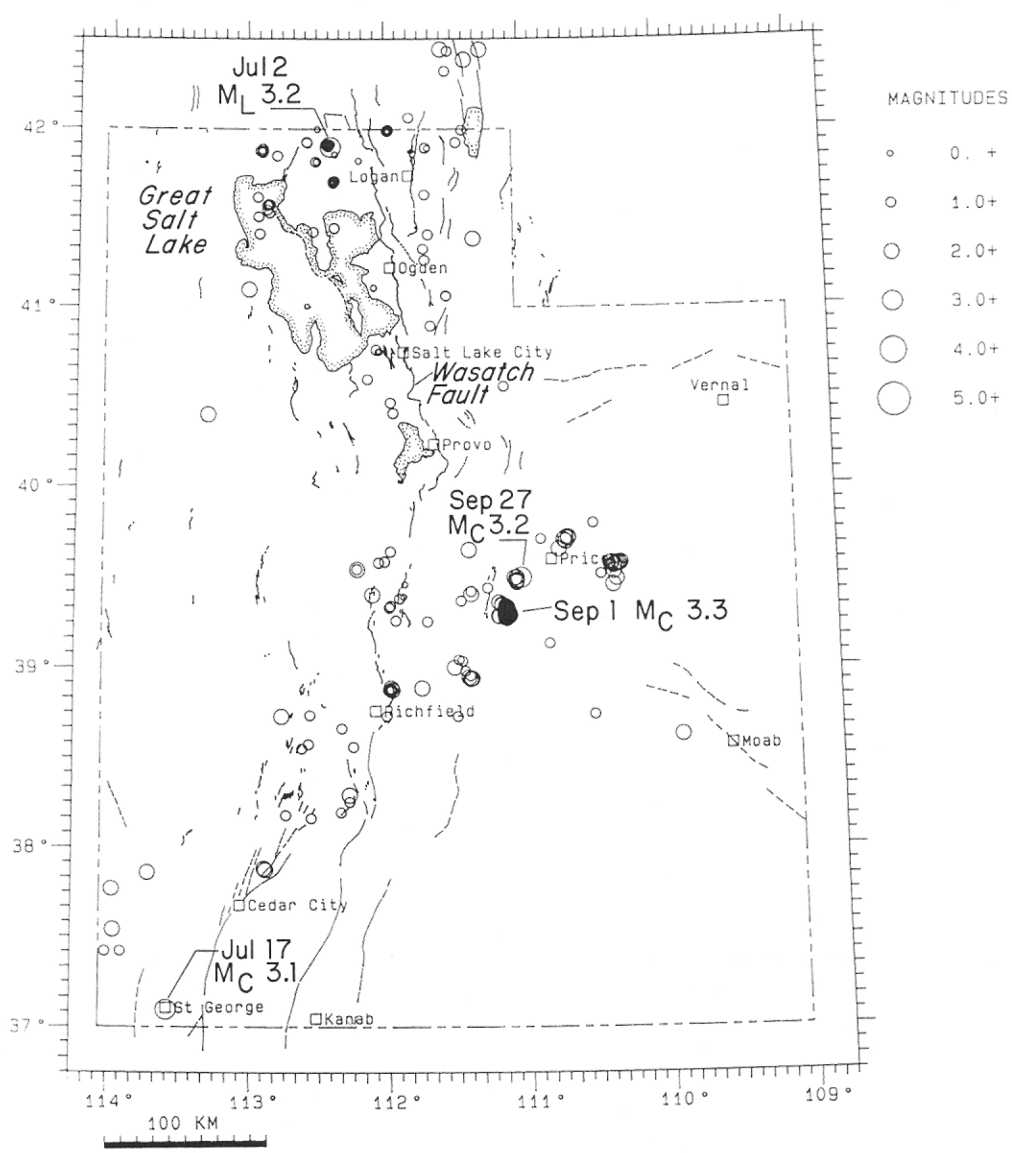
The USGS report comes on the heels of another report on the nation's regional seismograph networks. The National Research Council issued a report titled, *"Assessing the Nation's Earthquakes: The Health and Future of Regional Seismograph Networks."* The council found acute problems affecting regional networks, such as the University of Utah's, because of aging obsolete instrumentation and weakened capabilities resulting from nearly a decade of decreasing federal support.

The importance of regional seismograph networks, according to the council study, is that they play "an essential, if unrecognized, role far beyond that of simply monitoring earthquake activity." Other important parts of their mission, the report says, are rapid emergency response, scientific research, and acquiring information for earthquake engineering.

Earthquake Activity in the Utah Region

July 1 — September 30, 1990

Susan J. Nava
University of Utah Seismograph Stations
Department of Geology and Geophysics
Salt Lake City, UT 84112-1183
(801) 581-6274



During the three-month period July 1 through September 30, 1990, the University of Utah Seismograph Stations located 277 earthquakes within the Utah region (see accompanying epicenter map). Of these earthquakes, 118 had a magnitude (either local magnitude, M_L, or coda magnitude, M_C) of 2.0 or greater, and none were reported felt. There were four earthquakes of magnitude 3.0 or greater during this report period; their epicenters are specifically labeled on the epicenter map. (Note: All times indicated here are local time, which was Mountain Daylight Time during this period).

Four earthquakes of magnitude 3.0 and greater occurred in the Utah region during the report period: an M_L 3.2 event on July 2 at 9:05 p.m., located 13 km east of Howell; an M_C 3.1 event on July 17 at 7:33 p.m., located 1 km east of St. George; an M_C 3.3 event on September 1 at 12:12 p.m., located 11 km east of Orangeville; and an M_C 3.2 event on September 27 at 9:05 a.m., located 2 km east of Hiawatha.

Several clusters of earthquakes in the vicinity of Price appear on the epicenter map. The most dominant cluster, located 40 km to the southwest of Price, contains 85 shocks ranging in magnitude from 1.5 to 3.3. Earthquake activity in the areas to the east and southwest of Price is coal-mining-related seismicity, as observed for many years.

Additional information on earthquakes within the Utah region is available from the University of Utah Seismograph Stations.

Earthquake Ground Shaking in Utah

by Susan S. Olig

Of all the earthquake hazards in Utah, ground shaking has the potential to cause the most deaths, injuries, and property damage. Estimates for direct losses from damage to buildings caused by ground shaking exceed $5 billion (in 1985 dollars) for a M_S 7.5 earthquake on the Salt Lake City segment of the Wasatch fault zone (table 1; Algermissen and others, 1988).

There are three main reasons why ground shaking is a threat to so many Utahns:

***The hazard is extensive** — from Logan to St. George, from the Great Salt Lake to Kanab, the potential for damaging ground motion exists throughout much of the state (figure 1).

***The hazard is greatest in densely populated areas** — The largest ground motions are most probable along the central Wasatch Front. In fact, a detailed study indicates that the hazard is much greater from Brigham City to Nephi than was previously estimated.

***Ground shaking causes other hazards** — Strong ground motions can induce liquefaction (temporary liquefying of water-saturated fine sands), seiches (standing waves in lakes), snow avalanches, and slope failures. Because of the geology and physiography of our state (such as extensive fine-grained Lake Bonneville deposits, proximity of large bodies of water to population centers, and an abundance of steep terrain) many of these hazards are present in populated areas.

We cannot prevent earthquakes, and it is impossible to completely avoid the ground-shaking hazard in much of Utah. However, there are many reasonable things that can be done to significantly reduce the risk from ground shaking associated with earthquakes. This is because ground shaking itself does not injure or kill people; it is the failure of man-made structures that does. The severity of the hazard is extremely variable and depends on many factors. To efficiently target risk-reduction efforts, we need to understand and quantify those factors that affect damaging ground motions in Utah. To this end, significant progress has been made in many areas during the last ten years. However, some substantial gaps in our knowledge still remain. The following article highlights some important aspects of what we know and do not know about the ground-shaking hazard in Utah.

GROUND SHAKING AND BUILDING DAMAGE

The ground shaking we feel during earthquakes is a result of seismic waves reaching the earth's surface. The waves are generated at the source of the earthquake and travel through the earth, reflecting, refracting, interfering with one another, and resulting in a complex pattern of movements at the ground surface. How much damage is caused by the ground shaking depends on the amplitudes of the motions, the duration of strong shaking, the frequencies of ground vibrations, and the characteristics of the structures affected. Horizontal motions generally cause more damage than vertical motions because horizontal motions are typically larger, and because buildings are already designed to withstand vertical loads associated with gravity.

In general, larger magnitude earthquakes result in larger amplitudes of ground motions for a longer time period, which is why larger magnitude earthquakes typically cause more damage. Fortunately, energy is dissipated as the seismic waves travel through the earth, reducing the amplitudes and duration of strong shaking with increasing distance from the earthquake. However, there are many factors, besides magnitude and distance, that influence ground motions. Particularly important factors in Utah include the geometry and type of fault displacement, regional geology, and local geology (such as type and thickness of sediments at the surface, and depth to bedrock).

The frequencies of ground motions influence the damage caused by earthquakes because different types of structures are affected by different frequencies of shaking. An analogy can be made to a dog whistle and human hearing. Humans cannot hear the whistle, but dogs can because their ears are more sensitive to the particular frequencies produced by the whistle. Similarly, shorter buildings (1 to 2 stories) are generally more sensitive to, and are damaged more by, higher frequency motions (5 to 10 Hz), while taller buildings (10 to 20 stories) are generally more sensitive to lower frequencies (0.5 to 1 Hz). If the frequencies of the ground motions match the natural frequencies of vibration of buildings, then resonance, or constructive interference of the motions, can cause severe damage even at large distances from moderate-sized quakes.

TABLE 1.
Loss estimates for Weber, Davis, Salt Lake, and Utah Counties[1]. From Algermissen and others, 1988.

Location of scenario earthquake	Magnitude	% Loss[2]	Total Loss (1985 dollars)
Provo segment, Wasatch fault zone	5.5	3	830 million
	6.5	10	2.3 billion
	7.5	19	4.5 billion
Weber segment, Wasatch fault zone	5.5	5	1.3 billion
	6.5	13	3.1 billion
	7.5	22	5.2 billion
Salt Lake City segment, Wasatch fault zone	5.5	8	1.9 billion
	6.5	17	4.0 billion
	7.5	23	5.5 billion
Fault 50 km west of Salt Lake City	7.5	21	4.9 billion

[1]*Only includes commercial and residential buildings. Does not include schools, lifelines, or government buildings.*

[2]*Total loss ÷ total value in 1985 dollars x 100.*

MEASURING GROUND MOTIONS

Strong ground motions are typically recorded on accelerographs, rugged instruments that are specially designed to measure motions within the frequency band of engineering interest (roughly 1 to 10 Hz) and to not "clip" the record (so measure-

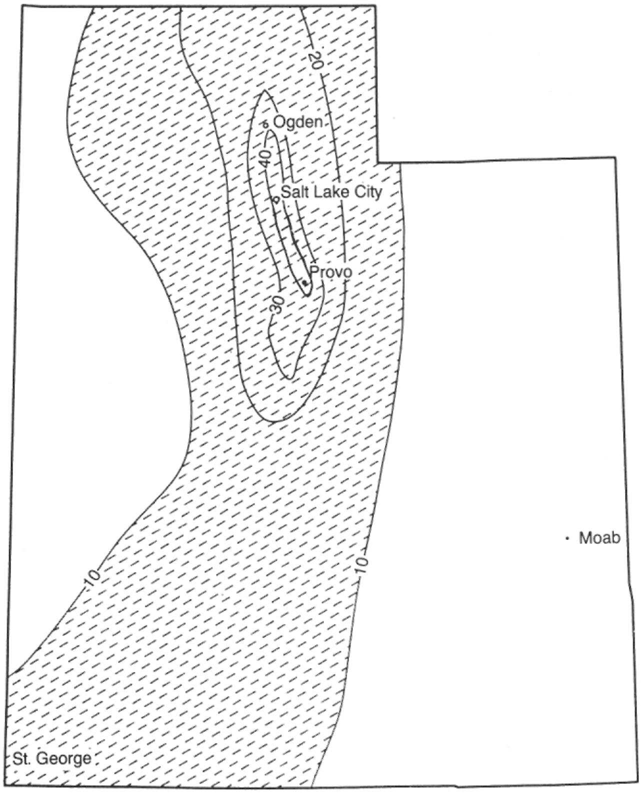


Figure 1. *Generalized map of the relative ground-shaking hazard in Utah. Shading shows area with a higher probability of experiencing damaging ground motions. Contours show peak horizontal accelerations (in percent g) on rock with a 10% chance of being exceeded in 50 years. Map does not show variations caused by local site conditions. Compiled from Algermissen and others (1990) and Youngs and others (1987).*

ments do not go off scale). Records are processed to determine ground accelerations, velocities, and displacements during the earthquake. This information is collected from many earthquakes and used to estimate ground motions associated with future earthquakes for safer and more efficient land-use planning and design of structures. It is also used to evaluate the performance of a structure during an earthquake. Accelerations are usually expressed in terms of "g", or the acceleration due to gravity (roughly 9.8 m/s^2 or 32 ft/s^2). The threshold for damage to weak structures (buildings not specifically designed to resist earthquakes) is roughly 0.1 g (Richter, 1958). Accelerations of 0.26 and 0.29 g were recorded close to the I-880 freeway overpass that collapsed during the 1989 Loma Prieta earthquake in California (Shakal and others, 1989). Maximum recorded accelerations have exceeded 2.3 g (Abrahamson and Litehiser, 1989).

Unfortunately, Utah is woefully lacking strong-motion records from earthquakes. Only one useable set of records exists. A peak acceleration of 0.12 g and a duration of 0.6 seconds were recorded 25 km (16 mi) from the epicenter of the 1962 Richmond earthquake (Smith and Lehman, 1979). Despite the relatively modest ground-motion amplitudes and the short duration, this M_L 5.7 earthquake caused nearly $1 million of damage (1962 dollars; Lander and Cloud, 1964), illustrating the power of even moderate-sized earthquakes to cause considerable damage, given certain conditions (figure 2).

ESTIMATING GROUND MOTIONS — EFFECTS OF GEOLOGIC FACTORS

Campbell (1987) estimates peak horizontal ground accelerations from 0.4 to 0.8 g, and peak velocities from 30 to 90 cm/s at a distance of 10 km (6.2 miles) for a M_S 7.5 earthquake in Utah. Ground motions of this severity would cause extensive damage in a metropolitan area. Even for a distance of 100 km (62 miles or roughly the distance from Ogden to Provo), Campbell (1987) estimates velocities between 2 and 10 cm/s. These motions are still potentially damaging, particularly to older, taller buildings.

The large range in the above estimates reflects both the large uncertainty in estimating ground motions in Utah and the expected variability due to differences in regional geology, fault rupture, and local geology. Because of the lack of strong-motion records in Utah, equations for predicting ground motion are based on data from other areas, particularly California. The equations are then modified, with significant uncertainty, to attempt to account for particular geologic and seismologic conditions in Utah. For example, it is controversial as to whether the continental crust in Utah dissipates seismic energy more than (King and Hays, 1977), less than (Singh and Herrmann, 1983), or comparable to (Langer, 1990) the continental crust in California, or indeed whether there are significant variations between different regions within Utah.

Because of the lack of strong-motion records in Utah, it is also uncertain how the type of fault displacement, fault geometry, and the direction of rupture propagation affect ground motions. Fault studies and observations of historical seismicity indicate earthquakes in Utah occur dominantly on dipping, normal faults (for example, Hecker, this issue; Arabasz and others, 1987). Studies have suggested that normal-slip earthquakes result in smaller ground motions than reverse- and strike-slip earthquakes (McGarr, 1984; Cocco and Rovelli, 1989), but Westaway and Smith (1989) recently analyzed normal-slip earthquakes worldwide and found no significant difference between peak ground accelerations caused by normal-slip earthquakes and accelerations caused by either reverse- or strike-slip earthquakes. In contrast, Campbell (1987) suggested that, at least close to the earthquake source, dipping faults cause larger motions than vertical strike-slip faults. Benz and Smith (1989) modeled the seismic response of the Salt Lake Valley to a simulated normal-slip earthquake on the Wasatch fault zone, which dips underneath the valley. They found that the direction of rupture propagation can increase ground motions within the valley, particularly along the fault trace. Obviously, the effects of these different source factors (fault type versus fault geometry versus the direction of rupture propagation) need to be resolved to better estimate ground motions in Utah.

How local geology affects ground motions associated with damaging earthquakes is probably the most significant factor for planning and design purposes in Utah. This is because the effects are large and can vary over small distances. Measurements along the Wasatch Front of distant explosions at the Nevada Test Site indicate that the motions in the frequency range of engineering interest were significantly amplified on sites underlain by sediments relative to rock sites (for example, Hays, 1987; King and others 1983, 1987). Amplifications were greater than 10 at some locations and were generally largest near the center of basins. However, the size and frequency-dependence of amplifications for nearby moderate- and large-magnitude earthquakes is still

Figure 2. *Damage to the bedroom of a brick house in Richmond, Utah, caused during the M_L 5.7 Richmond (Cache Valley) earthquake of August 30, 1962. The woman fortunately jumped out of bed prior to the bricks falling during the earthquake and she later posed for this picture. Photo by Ariel D. Benson, Richmond, Utah.*

uncertain. Depending on certain physical properties of the sediments, some sediments behave differently for small versus large ground motions. For example, amplifications measured at smaller accelerations might overestimate amplifications measured at larger accelerations (for a more extensive discussion see Hays, 1987).

Studies of earthquakes worldwide have demonstrated that near-surface "soft" sediments can amplify ground motions (Gutenberg, 1957; Seed and others, 1987; Borcherdt and others, 1989; Jarpe and others, 1989). "Soft" sediments have low shear-wave velocities (that is, seismic shear waves travel slowly through these sediments). An extensive drilling program conducted by the U.S. Geological Survey (USGS) identified many sites underlain by soft sediments along the Wasatch Front (J. C. Tinsley, USGS, oral communication, 12-27-89). Most of the sites are underlain by either fine-grained fluvial or lake deposits. Several studies attributed amplifications observed along the Wasatch Front entirely to shallow soft sediments (for example, Rogers and others, 1984).

Although shallow soft sediments are undoubtedly a major contributing factor to amplifications, recent theoretical studies of the Salt Lake Valley have shown that deep, steep-sided basins can also amplify and extend the duration of ground motions (Benz and Smith, 1989; Murphy, 1989; Hill and others, 1990). These studies are limited to simplistic models and low-frequency motions (2.7 Hz and less). However, they do indicate that deeper geologic boundaries within the basin can cause large amplifications for at least part of the frequency band of engineering interest. Indeed, the basin structure can account for more than 50% of the amplifications measured for the Nevada Test Site explosions at some sites (Murphy, 1989). These results have implications for other areas in Utah where Quaternary faults bound deep basins that underlie population centers, including Cedar City, Cache Valley, and much of the Wasatch Front. Current studies are attempting to better resolve how different aspects of the local geology affect ground motions in the Salt Lake Valley; the challenge comes in trying to quantify this effect without the benefit of strong-motion records from Utah.

There are many other factors that can also affect ground shaking; the ones mentioned here are the most significant that have been studied to date. Obviously, with so many factors and so little data, estimating ground motions for future earthquakes is no easy task and is fraught with uncertainty. Unfortunately, with only 25 accelerograph sites throughout all of Utah (as compared to over 700 in California), the prospects are unlikely for capturing strong-motion records of future earthquakes.

THE LIKELIHOOD OF DAMAGING GROUND MOTIONS

One way earth scientists can incorporate at least some of the uncertainty into estimating ground motions for future earthquakes is to use a probabilistic approach. A probabilistic evaluation gives an estimate of the likelihood of a certain event, such as a certain level of ground shaking in a given time period. For example, if you own an unreinforced brick home on firm soil in Salt Lake City, there is roughly a 1 in 3 chance that it will experience damaging ground shaking from earthquakes in 50 years (this is based on calculations using hazard curves from Youngs and others, 1987 and assumptions that the threshold of damage to an unreinforced brick home is about 0.1 g).

A considerable amount of information is needed to estimate such probabilities. First, potential sources of earthquakes in an area must be identified and characterized. This includes mapping Quaternary faults and other earthquake-generating geologic structures (for example, Hecker, this issue), as well as recording and locating historical earthquakes (for example, Nava, this issue). Additionally, parameters such as fault geometry, maximum expected magnitude, and rate of earthquake occurrence (including timing and size of past events) also need to be determined. In the last ten years, considerable progress has been made in identifying earthquake sources in Utah, particularly along the Wasatch Front. Detailed mapping and paleoseismic studies of several recently active faults outline a more complete picture of sources for large, surface-rupturing earthquakes (for a review see introduction to Lund and others, 1991).

Much of this information was incorporated into a detailed ground-shaking evaluation of the Wasatch Front by Youngs and others (1987). They mapped peak ground accelerations with a 10% chance of being exceeded in 10, 50, and 250 years from Nephi to the Utah-Idaho border. For the 50-year period, they estimated values greater than 0.4 g for rock sites in some areas (figure 1). Their estimates are much higher than the maximum estimates of 0.28 to 0.29 g from previous and recent studies that did not incorporate paleoseismic information in determining the rate of earthquake occurrence for the analysis (Algermissen and others, 1982, 1990). This is important because extrapolating the historical record of seismicity to determine the recurrence of large-magnitude earthquakes can significantly underestimate the hazard (Schwartz and Coppersmith, 1984). Algermissen and others (1982, 1990) used an average recurrence interval for M_S 7 and greater earthquakes along the entire Wasatch fault zone of approximately 720 years in their analysis, whereas Youngs and others (1987) used an average recurrence interval of 330 years (this is a combined value for both their segmented and unsegmented models). The 330-year estimate compares more favorably with the results from paleoseismic studies of the Wasatch fault zone (see "Earthquake Occurrence" in Christenson, this issue, and Hecker, this issue).

In regard to *using* the results from probabilistic ground-shaking studies, perhaps the toughest question that many communities face is "what is an acceptable level of risk?" This is especially difficult in Utah, where large earthquakes occur relatively infrequently. In designing a structure, should we use values that have a one-in-ten chance of being exceeded in 10, 50, 100, or 250 years? Or should some other criteria be used? How "safe" should our buildings be and how much are we willing to pay for it? Current codes are based on accelerations with a 10% chance of being exceeded in 50 years. However, national experts recently suggested that a lower level of risk is appropriate for certain design aspects in future codes, such as the equivalent of a 2.5% chance of being exceeded in 50 years (Whitman, 1989, p. 3-4), which is the same as a 10% chance of being exceeded in roughly 210 years (assuming a Poisson model or that earthquakes occur randomly in time).

Ultimately, determining appropriate design levels are societal issues with no easy answers, but results from geologic and seismologic studies demand that we address them. Because of relatively long recurrence intervals for large earthquakes, the hazard in Utah does not level off with increasing exposure time, as it does in California. Rather it continues to increase with time (figure 3). The implications of this are best illustrated by an example. A building in San Francisco designed for accelerations with a 10% chance of being exceeded during 50 years (roughly 0.78 g) also

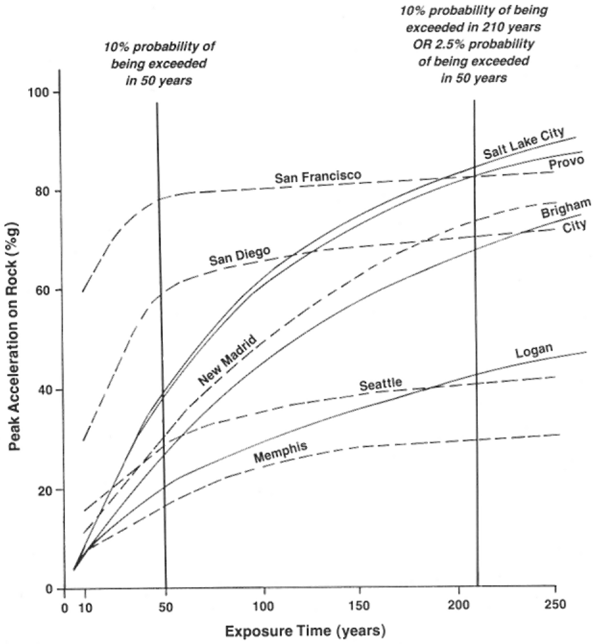


Figure 3. *Plot of accelerations on rock with a 10% probability of being exceeded during various time periods. See text for discussion. Dashed curves are from Algermissen (1988) and solid curves were calculated from results of Youngs and others (1987).*

has a 2.5% chance of experiencing accelerations greater than 0.81 g in 50 years, an insignificant increase of 0.03 g. In comparison, a building in Salt Lake City designed for accelerations with a 10% chance of being exceeded in 50 years (roughly 0.4 g) also has a 2.5% chance of experiencing accelerations greater than 0.8 g in 50 years, a substantial increase of 0.4 g above the design level (figure 3). With such large differences, deciding on an acceptable level of risk (for example a 2.5% versus a 10% chance of exceeding or somewhere in between) is obviously an important issue for Utah.

REDUCING THE RISK— UTAH'S BUILDING CODES

Because failure of man-made structures is the cause for most earthquake losses, engineers, building officials, and architects play a key role in reducing losses by improving development and construction practices. The following discussion summarizes recent progress in the use of building codes to reduce potential losses caused by ground shaking.

Until recently, requirements for earthquake-resistant design were left to the discretion of local jurisdictions. Many cities and counties in Utah independently adopted some version of the Uniform Building Code (UBC), which first included earthquake-resistant design provisions in the 1961 edition. Prior to 1961, the only requirements for buildings to resist horizontal forces in Utah were those determined by wind loads (Rogers and others, 1976). The UBC is continually revised and updated, and individual jurisdictions adopted new editions on their own schedules, making design requirements and enforcement extremely variable across the state. In 1987, the Utah State Legislature took a major step forward to reduce our risk from ground shaking by adopting the 1985 UBC statewide. This edition was superseded by the 1988 UBC, adopted statewide in 1989 as part of the Uniform Building Standards Act. This act also established the UBC Commission to oversee statewide implementation of the code.

Section 2312 of the 1988 UBC specifies minimum requirements for earthquake-resistant design of buildings. It applies to all new construction of most building types, including schools, hospitals, commercial and residential buildings, fire and police stations, power plants, and much more. The "Earthquake Regulations" in the code were extensively revised for the 1988 edition, but the basic philosophy remained the same, to establish minimum guidelines to protect lives during earthquakes. These guidelines also reduce potential structural damage caused by earthquakes. However, they do not ensure that structures or their contents will not suffer serious damage or even total loss, a painful lesson for building owners during several post-1961 earthquakes throughout the country (for example, Rogers and others, 1976, p. 90).

Two factors, Z and S, are defined in the 1988 UBC to quantify the minimum level of ground shaking that structures must be designed to withstand without collapse. No matter what design approach is used, minimum design criteria are ultimately tied to these two factors. The seismic zone factor, or Z, attempts to quantify ground motions on rock, and the site coefficient, or S, attempts to quantify the effects of near-surface sediments on the motions. Seismic zones range from 0 to 4, but only zones 1, 2b, and 3 are present on the 1988 map for Utah (figure 4). Specifically, Z is tied to accelerations on rock with a 10% chance of being exceeded in 50 years. Site coefficients range from 1.0 to 2.0 depending on the type and thickness of sediments underlying a

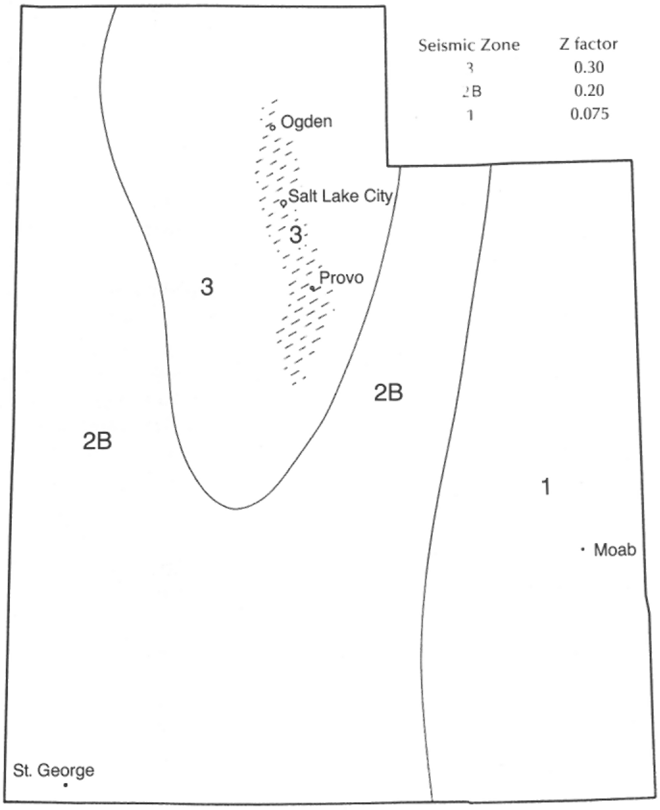


Figure 4. *The 1988 UBC seismic zone map for Utah. Shading shows area with accelerations greater than 0.3 g as mapped in figure 1. Combining this recent information and the criteria used by SEAOC to initially develop the 1988 seismic zone map, this area would fall into seismic zone 4. The UBC Commission has voted to submit an amendment to ICBO to change this area from zone 3 to zone 4, which will be considered for the 1994 edition of the code.*

site. Larger site coefficients attempt to account for larger amplifications of ground motions by near-surface sediments. One of the significant results from a U.S. Geological Survey drilling program was the identification of several sites along the Wasatch Front that qualify or nearly qualify for a maximum site coefficient of 2.0 (J. C. Tinsley, USGS, written communication, 6-4-90). There are no factors in the UBC which specifically account for other site effects, such as underlying basin geometry or topography.

The 1988 seismic zone map was initially based on criteria developed by the Structural Engineers Association of California (SEAOC) and on a nationwide map of accelerations with a 10% chance of being exceeded in 50 years by Algermissen and Perkins (1976). Subsequently, modifications of zone boundaries were made based on both technical and political considerations in an extensive review process by the International Conference of Building Officials (ICBO). If the original SEAOC criteria are combined with the new results from the Youngs and others (1987) study, the central part of the Wasatch Front would fall into seismic zone 4 (see shaded area in figure 4). Primarily based on this information, the UBC Commission has voted to submit an amendment to the ICBO to change the central Wasatch Front from zone 3 to zone 4. The amendment will be reviewed and considered for inclusion in the 1994 edition of the UBC.

Accurate determination of site coefficients and seismic zones are important, but this is ineffectual without adequate implementation of the earthquake regulations in the code. This is a multifaceted problem requiring education and enforcement. The UBC Commission is currently engaged in a massive education and training program to help building officials meet a 1993 statewide deadline for licensing. This program includes some training regarding earthquake regulations. In terms of enforcement, many building professionals are concerned that adequate plan checks are not being done and fees for building permits are being diverted toward other uses.

Finally, many studies have cited the high risk from ground shaking for the large number of older buildings in Utah (for example, Algermissen and others, 1988). Currently, the UBC Commission is reviewing the Uniform Code for Building Conservation for possible adoption statewide. This code applies to existing buildings and includes minimum guidelines for seismic retrofitting. However, this only deals with one aspect of the problem: retrofit of certain unreinforced masonry buildings during voluntary remodeling. The Seismic Committee of the Structural Engineers of Utah is currently reviewing different methods available for seismic retrofitting of buildings and has made this a top priority.

In summary, many groups have made progress toward reducing the ground shaking hazard in Utah by improving earthquake-resistant design and construction practices. However, much more work remains, including better building code enforcement, retrofitting of unsafe older structures, quantification of expected local variations of ground motions for design purposes, and a more detailed evaluation of the ground-shaking hazard in rapidly growing areas outside of the Wasatch Front (such as St. George). Overall, the most nagging problem facing those concerned with earthquake-resistant design in Utah is the lack of strong motion records. Without more data specific to the geologic conditions in Utah, there is considerable uncertainty as to how safe the current codes are and whether we may be overdesigning structures in some areas while underdesigning them in others.

REFERENCES

Abrahamson, N. A., and Litehiser, J. J., 1989, Attenuation of vertical peak acceleration: Bulletin of the Seismological Society of America, v. 79, p. 549-580.

Algermissen, S. T., 1988, Earthquake hazard and risk assessment — Some applications to problems of earthquake insurance: U.S. Geological Survey Open-File Report 88-669, p. 9-39.

Algermissen, S. T., Arnold, W. P., Steinbrugge, K. V., Hopper, M. G., and Power P. S., 1988, Earthquake losses in central Utah, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume III: U.S. Geological Survey Open-File Report 88-680, p. X-1-62.

Algermissen, S. T., Perkins, D. M., 1976, A probabilistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geological Survey Open-File Report 76-416, 45 p.

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p.

——1990, Probabilistic earthquake acceleration and velocity maps for the United States and Puerto Rico: U.S. Geological Survey Miscellaneous Field Studies Map MF-2120, scale 1:7,500,000.

Arabasz, W. J., Pechmann, J. C., and Brown, E. D., 1987, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume I: U.S. Geological Survey Open-File Report 87-585, p. D-1-58.

Benz, H. M., and Smith, R. B., 1988, Elastic-wave propagation and site amplification in the Salt Lake Valley, Utah, from simulated normal faulting earthquakes: Bulletin of the Seismological Society of America, v. 78, p. 1851-1874.

Borcherdt, R., Glassmoyer, G., Der Kiureghian, A., and Cranswick, E., 1989, Effect of site conditions on ground motions in Leninakan, Armenia S.S.R., *in* Borcherdt, R. D., editor, Results and Data from Seismologic and Geologic Studies Following Earthquakes of December 7, 1988, near Spitak, Armenia S.S.R., Volume I: U.S. Geological Survey Open-File Report 89-163A, p. 86-108.

Campbell, K. W., 1987, Predicting strong ground motion in Utah, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585, p. L-1-90.

Cocco, Massimo, and Rovelli, Antonio, 1989, Evidence for the variation of stress drop between normal and thrust faulting earthquakes in Italy: Journal of Geophysical Research, v. 94, p. 9399-9416.

Gutenberg, B., 1957, Effects of ground on earthquake motion: Bulletin of the Seismological Society of America, v. 47, p. 221-250.

Hays, W. W., 1987, Site amplification in the Salt Lake City-Ogden-Provo, Utah corridor and the implications for earthquake-resistant design, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585,p. K-1-69.

Hill, Julie, Benz, Harley, Murphy, Mary, and Schuster, Gerard, 1990, Propagation and resonance of SH waves in the Salt Lake Valley, Utah: Bulletin of the Seismological Society of America, v. 80, p. 23-42.

Jarpe, S. P., Hutchings, L. J., Hauk, T. F., and Shakal, A. F., 1989, Selected strong- and weak-motion data from the Loma Prieta earthquake sequence: Seismological Research Letter, v. 60, p. 167-176.

King, K. W., and Hays, W. W., 1977, Comparison of seismic attenuation in northern Utah with attenuation in four other regions of the western United States: Bulletin of the Seismological Society of America, v. 67, p. 781-792.

King, K. W., Hays, W. W., and McDermott, P. J., 1983, Wasatch Front urban area seismic response data report: U.S. Geological Survey Open-File Report 83-452, 66 p.

King, K. W., Williams, R. A., and Carver, D. L., 1987, Relative ground response in Salt Lake City and areas of Springville-Spanish Fork, Utah, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585, p. N-1-48.

Lander, J. F., and Cloud, W. K., 1964, United States earthquakes, 1962: U.S. Department of Commerce, Coast and Geodetic Survey, United States Earthquake Series, U.S. Government Printing Office, Washington, D. C., p. 112-113.

Langer, C. J., 1990, Seismology field investigations: U.S. Geological Survey Open-File Report 90-54, p. 86-87.

Lund, W. R., Schwartz, D. P., Mulvey, W. E., Budding, K. E., and Black, B. D., 1991, Fault behavior and earthquake recurrence on the Provo segment of the Wasatch Fault zone at Mapleton, Utah County, Utah: Paleoseismology of Utah, Volume I: Utah Geological and Mineral Survey Special Studies 75, 41 p.

McGarr, A., 1984, Scaling of ground motion parameters, state of stress, and focal depth: Journal of Geophysical Research, v. 89, p. 6969-6979.

Murphy, M.E., 1989, Finite-difference simulation of seismic P and SV-Wave amplification in the Salt Lake Valley, Utah: M.S. Thesis, University of Utah, 114 p.

Richter, C.F., 1958, Elementary seismology: W.H. Freeman and Co., San Francisco, 768 p.

Rogers, A. M., and others, 1976, A study of earthquake losses in the Salt Lake City, Utah, area: U.S. Geological Survey Open-File Report 76-89, 375 p.

Rogers, A. M., Carver, D. L., Hays, W. W., King, K. W., and Miller, R. D., 1984, Preliminary estimates of geographic variation in relative ground shaking in the Wasatch Front urban corridor, *in* Hays, W.W., and Gori, P.L., editors, A Workshop on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 547-556.

Schwartz, D. P., and Coppersmith, K. J., 1984, Fault behavior and characteristic earthquakes: Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, p. 5681-5698.

Seed, H. B., Romo, M. P., Sun, Joseph, Jaime, A., and Lysmer, J., 1987, Relationships between soil conditions and earthquake ground motions in Mexico City in the earthquake of September 19, 1985: University of California, Berkeley, Earthquake Engineering Research Center Report No. UCB/EERC-87-15, 112 p.

Shakal, A., Huang, M., Reichle, M., Ventura, C., Cao, T., Sherburne, R., Savage, M., Darragh, R., and Petersen, C., 1989, CSMIP strong-motion records from the Santa Cruz Mountains (Loma Prieta), California earthquake of 17 October 1989: California Division of Mines and Geology Report No. OSMS 89-06, 196 p.

Singh, S., and Herrmann, R. B., 1983, Regionalization of crustal Q in the continental United States: Journal of Geophysical Research, v. 88, p. 527-538.

Smith, R. B., and Lehman, J. A., 1979, Ground response spectra from the M_L5.7 Logan (Cache Valley) earthquake of 1962, *in* Arabasz and others, Earthquake Studies in Utah, 1850 to 1978: University of Utah Seismograph Stations Special Publication, p. 487-495.

Westaway, Rob, and Smith, R. B., 1989, Strong ground motion in normal-faulting earthquakes: Geophysical Journal, v. 96, p. 529-559.

Whitman, R. V., 1989, Workshop on ground motion parameters for seismic hazard mapping: National Center for Earthquake Engineering Research, Technical Report NCEER-89-0038.

Youngs, R. R., Swan, F. H., Power, M. S., Schwartz, D. P., and Green, R. K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, *in* Gori, P. L., and Hays, W. W., editors, Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585, p. M-1-110.

Director's Corner, continued.

So, where does the State Earthquake Program go from here? After two years of significant effort with the Utah Legislature, not a single bill has resulted. Costs of some measures doomed them, other bills just did not seem to get anyone's attention, and overall there was no sense of urgency to deal with the earthquake problem.

The UGMS and our partners in the program will continue to do what we can. The three groups have staff, expertise, and a strong sense of commitment. Progress is made every day. But our concern is that it won't be enough and it won't be done in time. Money is always a problem. CEM has more demands on its publications, speakers, and trainers than it can support. Reduced federal funding and lack of state support is threatening to reduce the contributions that the UUSS can make. Years of keeping the state seismic network operating by neglecting other research duties is coming to an end and the debt must be repaid. The desperately needed strong-motion program still has not received a dollar of funding. And what use is it if we scientists gather the best and most complete data possible, if society does not put it to use to reduce risks?

Over and over we hear "all we need is a moderate earthquake in Salt Lake City and things woulds happen." Unfortunate, but perhaps true.

Earthquake Legislation

"Many professionals, such as engineers, architects, and builders, share a responsibility to help protect the public from unacceptable risks from earthquakes."

by Gary E. Christenson

Earthquake preparedness, emergency response, and both short- and long-term recovery planning are complex processes that potentially affect and involve us all. To foster effective action, governmental entities (federal, state, and local government; school districts) must show leadership in supporting and funding programs addressing these important issues. Many professionals, such as engineers, architects, and builders, share a responsibility to help protect the public from unacceptable risks from earthquakes. This responsibility extends to the private individual who must look after personal and family preparedness.

To improve government preparedness, several groups have been working closely with Governor Norman H. Bangerter's office and the State Legislature to develop needed earthquake legislation. To date, the UGMS, Utah Division of Comprehensive Emergency Management, and University of Utah Seismograph Stations have been the principal advocates, informally constituting the State Earthquake Program. This advocacy group was enlarged considerably in the 1990 Legislature, following the October 17, 1989 Loma Prieta earthquake near San Francisco, when legislators concerned about earthquakes introduced six bills and one resolution addressing earthquake issues. This legislation covered issues as diverse as the assessment of the seismic vulnerability of schools, the need for new instrumentation to better understand earthquakes, earthquake education in schools, and local government hazards ordinances.

Unfortunately, no earthquake legislation was passed in the 1990 Legislature, but much was accomplished toward increasing lawmakers' awareness of the issues. Most of the legislation which did not pass was sent to interim study in preparation for the 1991 Legislature. Nearly all went to the State and Local Affairs Interim Committee, chaired by Senator K.S. Cornaby and Representative Afton Bradshaw, which devoted two full monthly meetings (May and June) and parts of several other meetings to discuss the issues. Also during the interim, Governor Bangerter asked the Utah Advisory Council on Intergovernmental Relations (ACIR) to take the lead in providing input from the executive branch of state government. In response to this request, the ACIR empaneled an Earthquake Task Force composed of 23 members representing state and local government, the private sector, and the various professions with a stake in earthquake issues. The Earthquake Task Force met in August and September to prioritize needed earthquake legislation and estimate costs to implement the legislation. A prioritized list was then provided to the State and Local Affairs Interim Committee to aid them in their deliberations. The Earthquake Task Force's principal recommendations for 1991 legislation, placed into groupings listed in order of priority, include:

Group 1

— Establish a Seismic Safety Commission to oversee and coordinate the state earthquake program.

Group 2

— Upgrade existing and acquire new earthquake instrumentation: a) modern seismic network instrumentation, b) strong-motion instrumentation for earthquake engineering, c) portable seismographs for data collection, d) communication systems for information transfer, and e) earthquake-deformation monitoring from global-positioning satellite measurements.

— Require that fees collected for building plan checks by local governments be used for this purpose to more effectively implement the Uniform Building Code structural/seismic provisions.

Group 3

— Seismic vulnerability assessments of schools, fire stations, and bridges.

— Training for disaster preparedness and urban search and rescue.

— Improve communications, including a microwave system for disaster communications and updated network design of radios, telecommunications, and microwave resources (cellular phones).

— Increase public awareness to improve personal and family preparedness.

Group 4

— Mandatory geologic-hazards site investigations for new critical government facilities.

— Require local governments to enact geologic-hazards ordinances.

— Geologic hazards disclosure in real-estate transactions.

Four earthquake bills were ultimately introduced into the 1991 legislature, three of which directly addressed the ACIR Earthquake Task Force's top priorities: 1) Natural Disaster Commission (HB 11; Donald LeBaron and Ray Nielsen, sponsors; also a State and Local Affairs "Committee-sponsored" bill), 2) Earthquake Instrumentation (HB 156, SB 169; Donald LeBaron and Craig Peterson, sponsors), 3) Seismic Vulnerability Assessment of Schools (HB 229; Kim Burningham, sponsor), and 4) Earthquake Insurance (HB 44; Gene Davis, sponsor).

As in 1990, none of the bills passed. The issue dealing with plan checks (see Group 2 above) was placed on the Interim Study Resolution for further consideration. The only bill passed that even indirectly addressed earthquakes was HB 9, Continuity of Government (Afton Bradshaw, sponsor). This bill would have ensured government continuity and succession in emergencies such as large earthquakes but it was vetoed by the Governor. Although the lack of action by the Legislature was disappointing, the base of support for earthquake hazard reduction measures among lawmakers and others has continued to grow through this process. Attempts to achieve the needed actions will also continue, although the emphasis may be shifted to other, more productive fronts.

Stratigraphy of Eastern Farmington Bay

by Ben Everitt
Chief Geologist, Division of Water Resources
Utah Department of Natural Resources

Between April 3rd and May 11th, 1990, a series of 100-foot hollow-stem auger holes was drilled in Farmington Bay to test foundation conditions for a proposed water-storage reservoir to be enclosed by dikes. Overland Drilling performed the work for Bingham Engineering under a contract with the Utah Division of Water Resources. Holes were drilled on a one-mile grid on section corners to get the "big picture" of stratigraphy and structure under the bay, and to measure the engineering properties of the sediments (figure 1). This is the first systematic drilling to be undertaken in eastern Farmington Bay, and it has produced some interesting stratigraphic and structural information.

Split spoon and California samples were taken at 5-foot intervals, and Shelby-tube samples taken at infrequent intervals. Two additional 50-foot holes, 9a and 9b (figure 1), were drilled to recover continuous core through a landslide deposit. A complete report of the drilling with the logs of the holes is contained in "Davis County Pond, Preliminary Design Report," Utah Division of Water Resources, September, 1990. The samples are available for study in the UGMS Sample Library.

STRATIGRAPHY

It was found that the sediments beneath the bay can be correlated between drill holes and in most of the area are roughly horizontal. Figure 2 is a fence diagram showing stratigraphic relations in the southeast corner of Farmington Bay. Despite the intermittent sampling, several samples of datable organic material and fossiliferous deposits were recovered. Four radiocarbon dates and 2 amino acid racemization ages have helped to refine the stratigraphic interpretation shown in figure 2.

A surface layer of soft, fetid, salty, gray clay underlies most of the bay with a thickness of 10 to 30 feet (Unit 1). An oolitic sand from near the bottom of the layer (14 feet in drill hole 16) gave a radiocarbon age of 8360 years (± 110 years) suggesting that the deposit is Holocene-aged off-shore sediment of the Great Salt Lake.

A large landslide was identified in drill holes 4, 9, and L6 on the basis of inclined and deformed bedding (Unit 2). The deposit is mostly a compact clay with a distinct oxidized brown coloring in the upper part, indicating deposition and weathering in a sub-aerial environment, apparently not that presently existing in the bottom of Farmington Bay. The clay is interlaminated with thin beds of fine sand, indicating a lacustrine origin. The deposit extends to a depth of 50 feet in drill hole 9, and 70 feet in holes 4 and L6. Its extent correlates well with the area of the younger Farmington Siding landslide (figure 1) mapped on shore by Van Horn (1973). The slide has been postulated to be a liquefaction-induced lateral spread, likely caused by earthquake ground shaking. The gentle gradient of the lower contact over a square mile indicates that it is the sole of a slide rather than a fault. There is no evidence of multiple slide planes; it is one single massive landslide. Continuous coring in drill holes 9a, 1000 feet north of hole 9, and drill hole 9b, 1000 feet east of hole 9, recovered both the top and bottom of the slide. Organic clay immediately overlying the landslide in hole 9a gave a radiocarbon age of 2930 years (±70 years). This date lies within the error bars of dates on the penultimate earthquake identified in studies of the Weber segment of the Wasatch fault zone (Foreman and others, in press).

Elsewhere beneath the Great Salt Lake mud (Unit 1) are interbedded sand and clay of a different character. Moderately well-sorted quartz sand and finely laminated clay, silt, and fine sand suggest a higher energy environment. The "upper sand" (Unit 3 of figure 2) thickens northward and is very likely the Lake Bonneville regressive sand at the edge of the Weber Delta, but it could be partly related to the Gilbert lake expansion between 9,000 and 12,000 years ago (Murchison, 1989, figure 40). In the transitional interbedded sand and clay beneath it (Unit 4), an oolitic sand was found at a depth of 43 feet in hole 14, indicating shallow saline lake conditions.

Below the regressive sand (Units 3 and 4) is a unit of massive to thinly laminated gray clay up to 50 feet thick (Unit 5). It fits the Bonneville model as the deepwater facies, except for the layer of shrimp pellets at 63 feet in hole 18. Perhaps these are not brine shrimp, but Lake Bonneville deepwater shrimp.

Beneath the clay is another relatively thin sand (Unit 6) interpreted as the Lake Bonneville transgressive sand. Very fossiliferous, it contains wood, peaty marsh deposits, snails, and clams. Dated materials give ages ranging from 25,000 to 30,000 years (figure 2). This "lower sand" also contains natural gas under sufficient pressure in some drill holes to blow the column of water out of the hollow stem of the augers. Analysis provided by the UGMS shows the gas to be mostly methane with some carbon dioxide.

The few holes which penetrated below the transgressive sand returned more interbedded gray sand and clay.

STRUCTURE

The measured thicknesses and ages of sediment suggest a greater rate of deposition in eastern Farmington Bay than elsewhere in the Great Salt Lake. This is consistent with the position of the eastern bay adjacent to the Wasatch fault zone on the downthrown side. However, there is no evidence for deformation except in the area interpreted as the toe of the Farmington Siding landslide. At the southern edge of the area, north of drill holes 1, 2, and 3, the deeper layers as defined by the top of Unit 6 dip northward up to 40 feet per mile, but there is no surface expression of this structure. There is no pronounced eastward dip, as would be expected if the lake bed had been repeatedly downdropped and tilted during surface-faulting earthquakes on the Wasatch fault zone in post-Bonneville time.

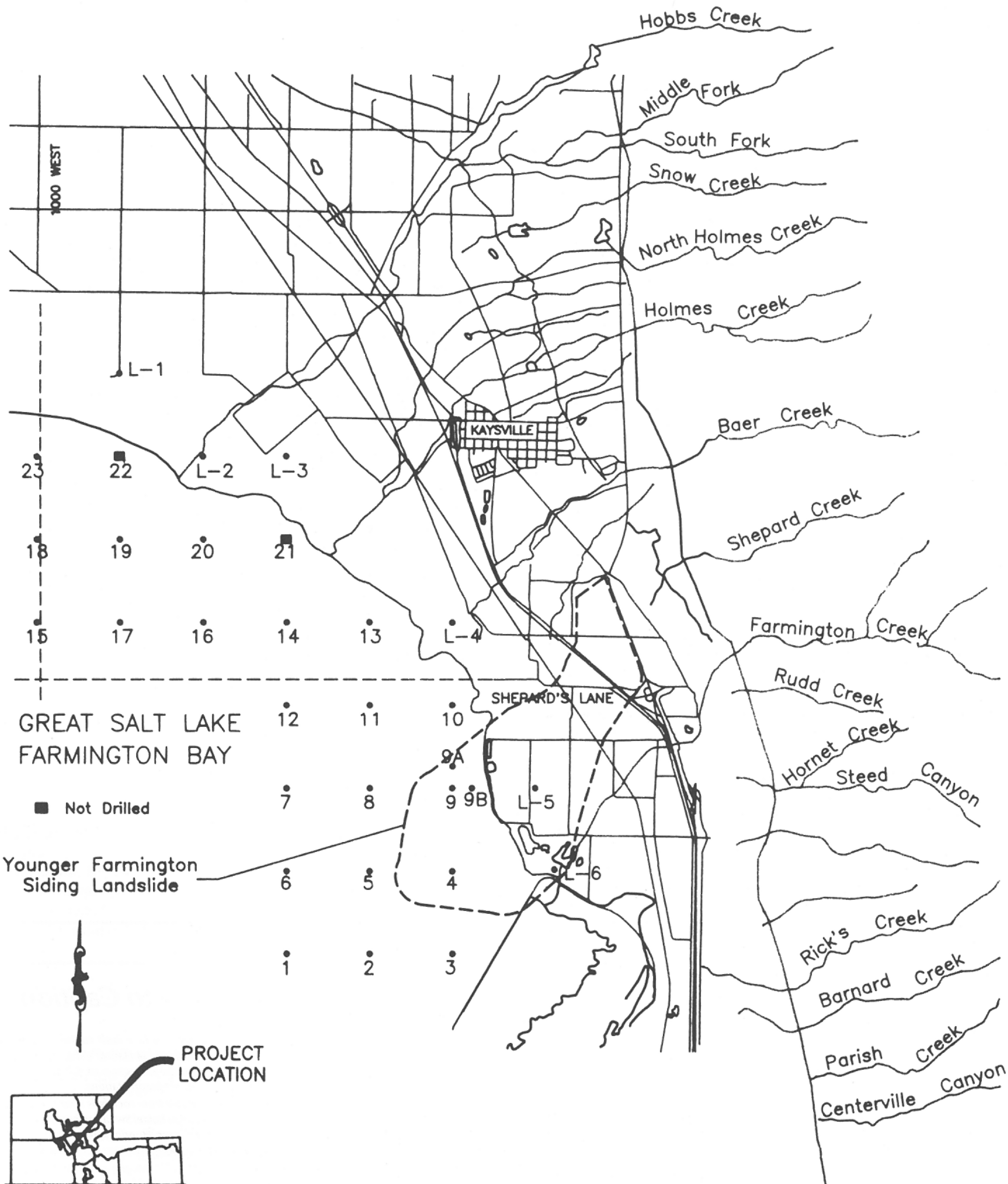


Figure 1. *Drill hole locations in Farmington Bay.*

LANDSLIDE

The great thickness of the landslide is surprising. Its massive structure bears little resemblance to the shallow exposures of jumbled and partially liquefied sandy material in the Farmington Siding landslide area. Either they are not the same features, or the Farmington Siding landslide is more complex than had been thought.

There is very little sand associated with the landslide sole. The sandy beds (Units 3 and 4) are missing beneath the slide, which rests in all holes directly on clay (Unit 5). It is possible that the sandy units liquefied during the event and flowed out in front of the slide. Low to moderate blow counts in Units 3 and 4 indicate that it has the potential to liquefy during a magnitude 7.5 earthquake on the nearby Weber segment.

The sheared layer in the landslide sole is 5 feet or less in thickness and consists of packets of tightly folded clay between thin faults. The deformed clay is not noticeably weaker than the undeformed clay and, in general, the clays of the landslide mass have higher strengths than the clays found in the rest of the project area. Some clays outside the landslide area were found to lose strength on remolding, but none can be called "sensitive," that is, having remolded strength less than 1/10th of its undeformed strength.

REFERENCES

Foreman, S.L., Nelson, A.R., and McCalpin, J.P., in press, Thermoluminescence dating of fault-scarp derived colluvium: Deciphering the timing of paleoearthquakes on the Weber Segment of the Wasatch Fault Zone, north-central Utah: Journal of Geophysical Research.

Murchison, Stuart B., 1989, Fluctuation history of Great Salt Lake, Utah, during the last 13,000 years: University of Utah Limneotectonics Laboratory Technical Report 89-2, 137 p.

Van Horn, Richard, 1973, Largest known landslide of its type in the United States — A failure by lateral spreading in Davis County, Utah: Utah Geological and Mineralogical Survey, Utah Geology, v. 2, no. 1, p. 83-88.

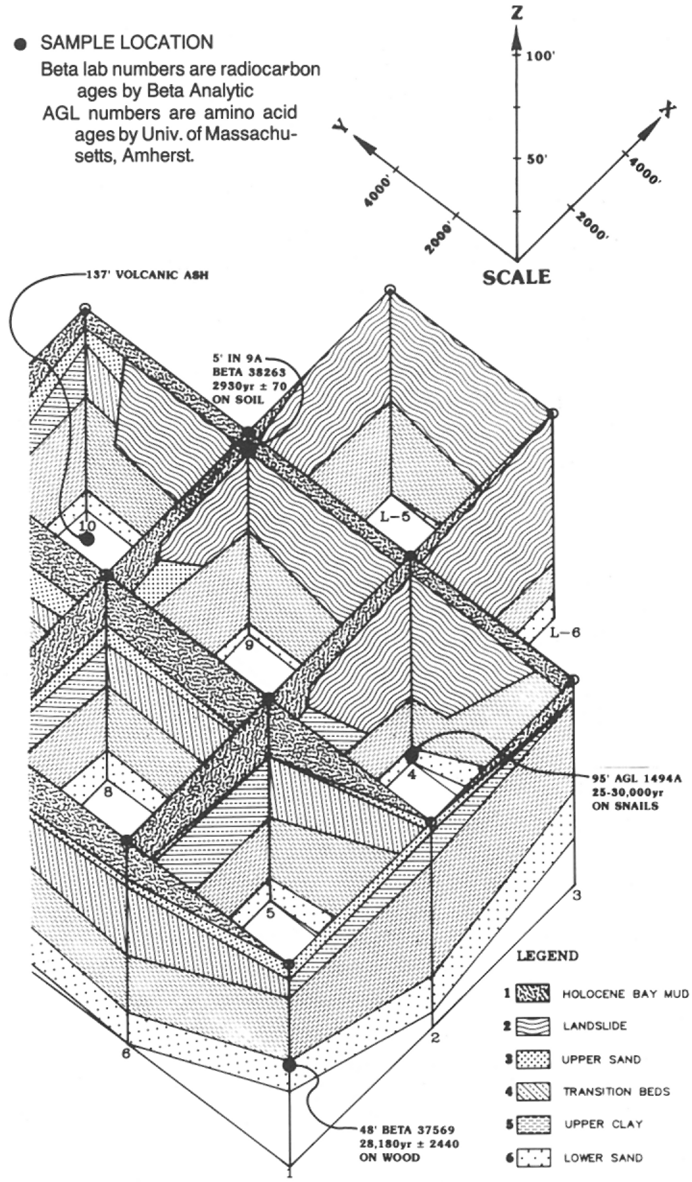
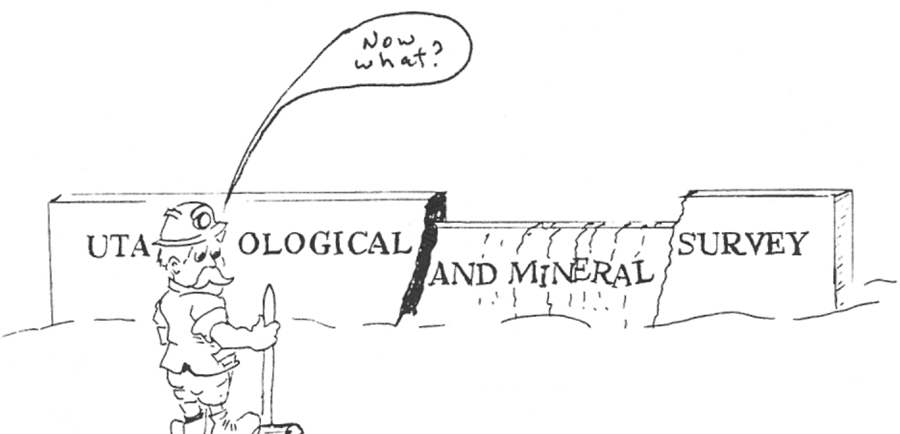


Figure 2. *Fence diagram of generalized stratigraphy, Farmington Bay.*



Cover Photo Captions

Top left and center. *Surface fault rupture along the Hansel Valley fault in the 1934 Hansel Valley earthquake (M_L 6.6). Photos from the collection of Robert B. Smith, University of Utah Seismograph Stations.*

Top right. *Dust clouds from rock falls near Huntington triggered by the 1988 San Rafael Swell earthquake (M_L 5.3). Photo by Darrel Leamaster, Huntington, Utah.*

Middle right and lower right. *Damage to houses in Salt Lake City during the 1962 Magna earthquake (M_L 5.2). Photos courtesy of Sherrry D. Oaks and the Deseret News.*

Lower left. *Fault scarp formed in the 1983 Borah Peak, Idaho earthquake (M_S 7.3) displacing a concrete-lined ditch. Note left-lateral as well as vertical displacement. Photo by Robert C. Rasely, U.S. Soil Conservation Service.*

Books & Papers

This is an information list only. The UGMS does not have these publications.
Papers listed as U.S.G.S. may be purchased by contacting U.S.G.S. Earth Science Information Center (in Salt Lake: 801-524-5652).

A new Utah Energy Office publication is available for individuals interested in obtaining comprehensive information on Utah's energy resources. The report, ***Utah Energy Statistical Abstract,*** provides detailed statistical information on production, consumption, distribution, reserves and prices for Utah's primary energy sources — coal, petroleum, natural gas, electricity and uranium. The 160-page report, compiled by the Utah Energy Office's Resource Development Section, is the third edition of the *Statistical Abstract*. It contains historical data from 1960-1988 presented in comprehensive tables and supporting graphs. Cost of the *Abstract* is $10 and is available by contacting Denise Beaudoin, Utah Energy Office information specialist at 538-5410 or 662-3633.

Mineral resources of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Grand County, Utah, by R.P. Dickerson, J.D. Gaccetta, D.M. Kulik, U.S. Geological Survey; and T.J. Kreidler, U.S. Bureau of Mines. 1990. p. A1-A29. 1 plate in pocket. U.S.G.S. Bull. 1753-A. $2.25

Hydrologic characteristics of the Great Salt Lake, Utah; 1847-1986, by Ted Arnow and D.W. Stephens, 1990. 32 p. 1 plate in pocket. U.S.G.S. Water-Resource Bull. 2332. . . . . $5.00

The 1987 estimate of undiscovered uranium endowment in solution-collapse breccia pipes in the Grand Canyon region of northern Arizona and adjacent Utah, by W.I. Finch, H.B. Sutphin, C.T. Pierson, R.B. McCammon and K.J. Wenrich. Prepared in cooperation with the U.S. Department of Energy, Energy Information Administration. 1990. 19 p. U.S.G.S. Circular 1051. . . . . Free.

Preliminary assessment of the mineral resources of the Cedar City 1° x 2° Quadrangle, Utah, by R.G. Eppinger, G.R. Winkler, T.M. Cookro, M.A. Shubat, H.R. Blank, J.K. Crowley, R.P. Kucks and J.L. Jones. Prepared in cooperation with the Utah Geological and Mineral Survey, 1990. 142 p., 1 over-size sheet, scale 1:250,000. U.S.G.S. Open-File Report 90-0034.

Experimental digital shaded-relief maps of Utah, by Kathleen Edwards and R.M. Batson. 1990. Two sheets, each 1:1,000,000 (1 inch = about 16 miles). U.S.G.S. Map I-1847. . . . . $5.50

Geologic map of the Price 30' x 60' Quadrangle, Carbon, Duchesne, Uintah, Utah, and Wasatch counties, Utah, by MP. Weiss, Northern Illinois University; I.J. Witkind, and W. B. Cashion, U.S. Geological Survey, 1990. Scale 1:100,000 (1 inch = about 1.6 miles). U.S.G.S. Map I-1981. . . . . $3.10

Geologic map and coal stratigraphy of the Needle Eye Point Quadrangle, Kane County, Utah, by H.D. Zeller. 1990. Scale 1:24,000 (1 inch = 2,000 feet). U.S.G.S. Map C-0129. . . . . $3.10

Geologic map and coal stratigraphy of the East of the Navajo Quadrangle, Kane County, Utah, by H. D. Zeller. 1990. Scale 1:24,000 (1 inch = 2,000 feet). U.S.G.S. Map C-130. . . . . $3.10

Geologic map and coal stratigraphy of the Ship Mountain Point Quadrangle and the north part of the Tibbet Bench Quadrangle, Kane County, Utah, by H.D. Zeller and G.E. Vaninetti. 1990. Scale 1:24,000 (1 inch = 2,000). U.S.G.S. Map C-0131. . . . $3.10

Geologic map and coal stratigraphy of the Petes Cove Quadrangle, Kane County, Utah, by H.D. Zeller. 1990. Scale 1:24,000 (1 inch = 2,000). U.S.G.S. Map C-0132. . . . . $3.10

Mineral resources of the Cockscomb and Wahweap Wilderness Study Areas, Kane County, Utah, by Henry Bell III, J.E. Kilburn, J.W. Cady, U.S. Geological Survey; and M. E. Lane, U.S. Bureau of Mines. 1990. p. A1-A18. 1 plate in pocket. U.S.G.S. Bulletin 1748-A. $3.75

Mineral resources of the Mount Pennell Wilderness Study Area, Garfield County, Utah, by R.F. Dubiel, C.S. Bromfield, S.E. Church, W.M. Kemp, M.J. Larson, Fred Peterson, C.T. Pierson, U.S. Geological Survey; and D.D. Gese, U.S. Bureau of Mines. 1990. p. D1-D17. 1 plate in pocket. U.S.G.S. Bull. 1751-D. $3.75

Gold in porphyry copper systems, by E.W. Tooker, U.S. Geological Survey; L.P. James, BHP-Utah Minerals International; T.G. Theodore, S.S. Howe, U.S. Geological Survey; and D.W. Black, Battle Mountain Gold Exploration. 1990. p. E1-E55. And ***Gold in the Bingham District, Utah,*** by E.W. Tooker, U.S.G.S. p. E1-E16. U.S.G.S. Bull. 1857-E.

Reducing earthquake hazards in Utah; the crucial connection between researchers and practitioners, by W.J. Kockelman. 1990. 120 p. U.S.G.S. Open-File Report 90-0217.

Analytical results for gold in 1412 stream-sediment samples from the Richfield 1° x 2° Quadrangle, Utah, by J.B. McHugh and W.R. Miller. 1990. 20 p. U.S.G.S. Open-File Report 90-0237. . . . .

Preliminary surficial geologic map of the Weber Segment, Wasatch fault zone, Weber and Davis counties, Utah, by A.R. Nelson and S.F. Personius. 1990. Scale 1:50,000 (1 inch = about 4200 feet). Accompanied by 22-page text. U.S.G.S. Map MF-2132. . . . . $1.50

UGMS serves as an outlet for the University of Utah Seismograph Stations publications.
Their primary catalog and all the updates are listed below,
as well as other publications relating to their activities.

Miscellaneous Publication 87-7 Earthquake studies in Utah, 1850 to 1978, edited by W.J. Arabasz, R.B. Smith, and W.D. Richins, (reprint), 552 p., 1987. [This is the first catalog of Utah seismic events]. $28.00

Miscellaneous Publication F-1 Earthquake data for the Utah region, July 1, 1978 to December 31, 1980 by W.D. Richins and others 127 p., 1981. . . . . $5.00

Miscellaneous Publication F-2 Earthquake data for the Utah region, January 1, 1981 to December 31, 1983, by W.D. Richins and others, 111 p., 1984. . . . . $5.00

Miscellaneous Publication F-3 Earthquake data for the Utah region, January 1, 1984 to December 31, 1985, by W.D. Richins and others, 83 p., 1986. . . . . $5.00

Miscellaneous Publication F-4 Earthquake data for the Utah region January 1, 1986, to December 31, 1988, by S.J. Nava and others, 96 p., 1990 . . . . $6.00

Miscellaneous Publication L Seismic Safety Advisory Council Reports — Utah, reprinted in 3 volumes, 900 p., 1981. . . . $30.00

Miscellaneous Publication 91-1 A guide to reducing losses from future earthquakes in Utah — Consensus document, edited by W.J. Arabasz, 30 p., 1991. . . . . $5.00

Open-File Report 168 Earthquake instrumentation for Utah, report and recommendations of the Utah Policy Panel on Earthquake Instrumentation, edited by W.J. Arabasz, 164 p., 1990. . . . . $13.00

New Publications from UGMS

Geologic map of the Roger Peak quadrangle, Garfield County, Utah, by G.W. Weir, V.S. Williams, and L.S. Beard, 7 p., 2 pl., 1:24,000, 1990. Map 115. . . . . $5.00

Geologic map of the Escalante quadrangle, Garfield County, Utah, by V.S. Williams, G.W. Weir, and L.S. Beard, 6 p., 2 pl., 1:24,000, 1990. Map 116. . . . . $5.00

Geologic map of the Red Breaks quadrangle, Garfield County, Utah, by G.W. Weir and L.S. Beard, 5 p., 2 pl., 1:24,000, 1990. Map 117. . . . . $5.00

Geologic map of the Tenmile Flat quadrangle, Garfield County, Utah, by G.W. Weir and L.S. Beard, 6 p., 2 pl., 1:24,000, 1990. Map 118. . . . . $5.00

Geologic map of the King Bench quadrangle, Garfield County, Utah, by G.W. Weir and L.S. Beard, 5 p., 2 pl., 1:24,000, 1990. Map 119. . . . . $5.00

Geologic map of the Calf Creek quadrangle, Garfield County, Utah, by G.W. Weir and L.S. Beard, 5 p., 2 pl., 1:24,000, 1990. Map 120. . . . . $5.00

Geologic resources of Summit County, Utah, by M.H. Bugden and C.M. Wilkerson, 23 p., 1990. Public Information Series 7. . . . . $3.50

Great Salt Lake information sheet, 1 p., 1990. Public Information Series 8. . . . . Free

Geologic map of Antelope Island, Davis County, Utah, by H.H. Doelling, G.C. Willis, M.E. Jensen, S. Hecker, W.F. Case, and J.S. Hand, 27 p., 2 pl., scale 1:24,000, 1991. UGMS Map 127. . . . . $11.00

Geologic map of the Crater Island quadrangle, Box Elder County, Utah, by D.M. Miller, T.E. Jordan, and R.W. Allmendinger. 16 p., 2 pl., 1:24,000, 1990. UGMS Map 128. . . . . $5.00

Geologic map of the Crater Island SW quadrangle, Box Elder County, Utah, by D.M. Miller, 8 p., 2 pl., 1:24,000, 1990. UGMS Map 129. . . . . $5.00

Geologic map of the Lucin 4 SW quadrangle, Box Elder County, Utah, by D.M. Miller, 13 p., 2 pl., 1:24,000, 1990. UGMS Map 130. . . . . $5.00

Provisional geologic map of the Juab quadrangle, Juab County, Utah, by Donald L. Clark, 14 p., 2 pl., 1:24,000, 1990. UGMS Map 132. . . . . $5.00

Coalbed methane resource map, Castlegate A bed, Book Cliffs coal field, Utah, by Alec C. Keith, John S. Hand, and A.D. Smith, 1 pl., 1:100,000. 1990. UGMS Open-File Report 176A. $2.00

Coal bed methane resource map, Castlegate B bed, Book Cliffs coal field, Utah, by A.C. Keith, J.S. Hand, and A.D. Smith, 1 pl., 1:100,000, 1990. UGMS Open-File Report 176B. $2.00

Coal bed methane resource map, Castlegate C bed, Book Cliffs coal field, Utah, by A.C. Keith, J.S. Hand, and A.D. Smith, 1 pl., 1:100,000, 1990. UGMS Open-File Report 176C. $2.00

Coal bed methane resource map, Gilson bed, Book Cliffs coal field, Utah, by A.C. Keith, J.S. Hand, and A.D. Smith, 1 pl., 1:100,000, 1990. UGMS Open-File Report 176D. $2.00

Stratigraphy and paleogeography of Late Cretaceous and Paleogene rocks of southwest Utah, by P.M. Goldstrand, 58 p., 1990. Miscellaneous Publication 90-2. . . . . $6.00

Geologic map of the Sunset Pass quadrangle, Box Elder County, Utah, by D.M. Miller and J.D. Schneyer, 36 p., 2 pl., 1990. Open-File Report 201. $6.00

Quaternary geology of the Scipio Valley area, Millard and Juab Counties, Utah, by Charles G. Oviatt, 60 p., 1 pl., 1:62,500, July 1990. UGMS Open-File Report 187. . . $6.00

Cleat and joint system evaluation and coal characterization of the Castlegate "A" coal, Beaver Creek No. 8 Mine, Carbon County, Utah, by Brigitte Hucka, 29 p., January, 1991. UGMS Open-File Report 202. . . . . $2.50

Cleat and joint system evaluation and coal characterization of the Sunnyside coal, Soldier Canyon Mine, Carbon County, Utah, by Brigitte Hucka, 29 p., January, 1991. UGMS Open-File Report 203. . . . . $2.50

Fountain Green South quadrangle, Juab and Sanpete Counties, by A.W. Fong, 106 p., 2 pl., January, 1991. UGMS Open-File Report 204. . . . . $10.50

Geologic map of the Smelter Knolls West quadrangle, Millard County, Utah, by L.F. Hintze and C.G. Oviatt, 52 p., 2 pl., February 1991. UGMS Open-File Report 205. . . . . $7.00

Geologic map of the New Harmony quadrangle, Washington County, Utah, by S.K. Grant, 37 p., 2 pl., February 1991. UGMS Open-File Report 206. . . . . $6.00

Mines and prospects containing gold in Utah," by M.A. Shubat, B.T. Tripp, C.E. Bishop, and R.E. Blackett, 28 p., 2 pl., scale 1:750,000. UGMS Open-File Report 207. . . . . $5.25

Provisional geologic map of the Alton quadrangle, Kane County, Utah, by Terry L. Tilton, 46 p., 2 pl., February 1991. UGMS Contract Report 91-1. . . . . $7.00

Provisional geologic map of the Podunk Creek quadrangle, Kane County, Utah, by Terry L. Tilton, 46 p., 2 pl., February 1991. UGMS Contract Report 91-2. . . . . $7.00

Flood potential factors of rainstorms in central Davis County, Utah, by Scott R. Williams, 110 p., 2 pl., February 1991. UGMS Contract Report 91-3. . . . . $10.00

The geology and production history of the uranium-vanadium deposits in Monument Valley, San Juan County, Utah, by William L. Chenoweth, 56 p., 2 pl., February 1991. UGMS Contract Report 91-4. . . . . $8.00

Gold occurrence in the Cretaceous Mancos Shale, Eastern Utah, by Gordon Marlatt, 21 p., February 1991. UGMS Contract Report 91-5. . . . . $3.00

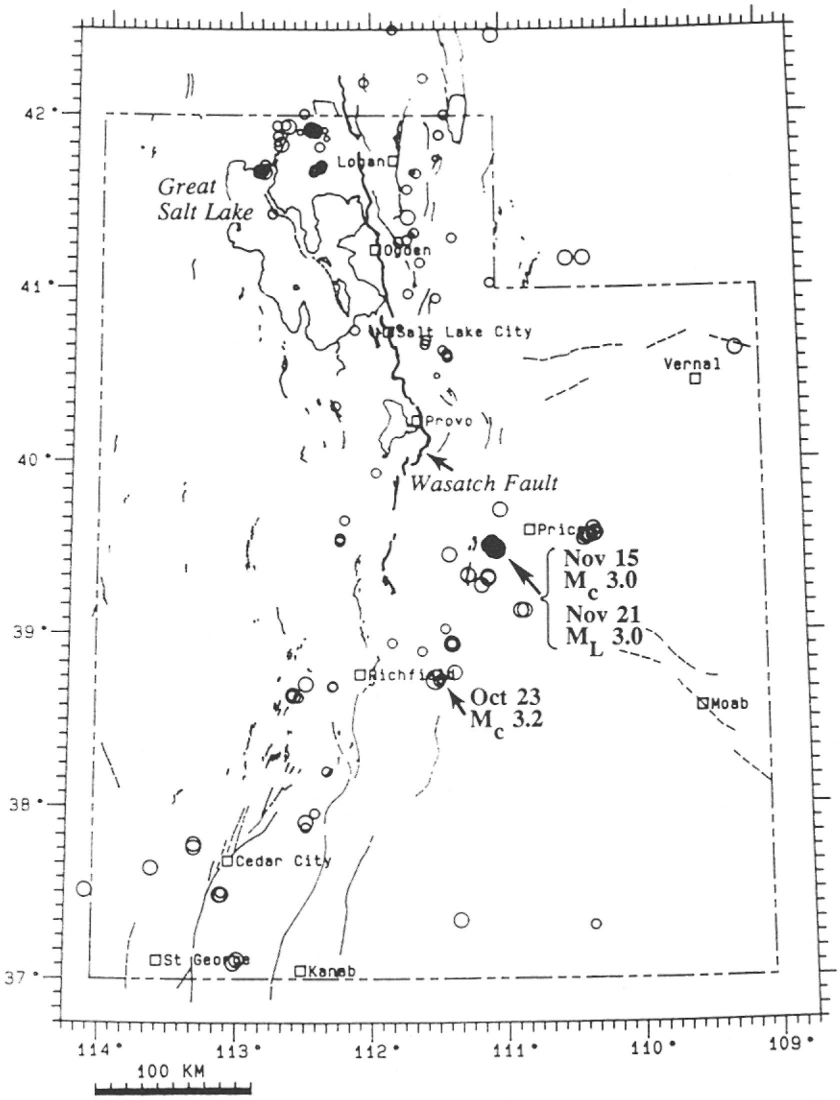
Prices include shipping but not Utah sales tax of 6.25%

—SALES—

Utah Geological and Mineral Survey
606 Black Hawk Way
Salt Lake City, UT 84108-1280
(801) 581-6831, FAX 581-4450

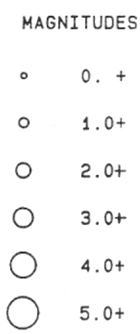
A NEW PUBLICATIONS LIST — APRIL 1991 — IS AVAILABLE FREE ON REQUEST.

Earthquake Activity in the Utah Region



October 1 — December 31, 1990

by Susan J. Nava
University of Utah Seismograph Stations
Department of Geology and Geophysics
Salt Lake City, UT 84112-1183
(801) 581-6274



During the three-month period October 1 through December 31, 1990, the University of Utah Seismograph Stations located 168 earthquakes within the Utah region (see accompanying epicenter map). The total includes three earthquakes in the magnitude 3 range, specifically labeled on the epicenter map, and 66 in the magnitude 2.0 range. (Note: Magnitude indicated here is either local magnitude, M_L, or coda magnitude, M_C. All times indicated here are local time, which was Mountain Daylight Time from October 1 through 27, and Mountain Standard Time from October 28 through December 31.)

Larger and/or Felt Earthquakes:

- M_C 3.2 October 23, 2:49 a.m. 32 km west of Emery
- M_C 3.0 November 15, 7:08 a.m. 9 km west of Hiawatha
- M_L 2.6 November 20, 1:19 a.m. 13 km southeast of Castle Dale *(Only felt earthquake during report period: felt locally in the towns of Clawson, Ferron, and Castle Dale.)*
- M_L 3.0 November 21, 5:16 a.m. 5 km west of Hiawatha

Significant Clusters of Earthquakes:

- Near Price (coal-mining related): Two clusters located to the east and to the southwest of Price contain 8 and 23 shocks, respectively, ranging in magnitude from 1.5 to 3.0.
- North of the Great Salt Lake: Three clusters of earthquakes make up 35% of the shocks that occurred in the Utah region during the report period.

  —60 km northwest of Logan: 29 earthquakes, magnitude 0.4 to 2.2, occurred primarily in late November and early December.

  —50 km west of Logan: 9 earthquakes, magnitude 0.7 to 1.8, occurred in the same location of an M_L 4.8 shock in July 1989.

  —85 km west of Logan (along the northern arm of the Great Salt Lake): 11 earthquakes, magnitude 1.0 to 2.6.

  This is one of the most seismically active regions of Utah, and the observed activity is not unusual.

Additional information on earthquakes within the Utah region is available from the University of Utah Seismograph Stations.

UTAH DEPARTMENT OF NATURAL RESOURCES
Utah Geological and Mineral Survey
606 Black Hawk Way
Salt Lake City, Utah 84108-1280

Address correction requested
Survey Notes

BULK RATE
U.S. POSTAGE PAID
S.L.C., UTAH
PERMIT NO. 4728